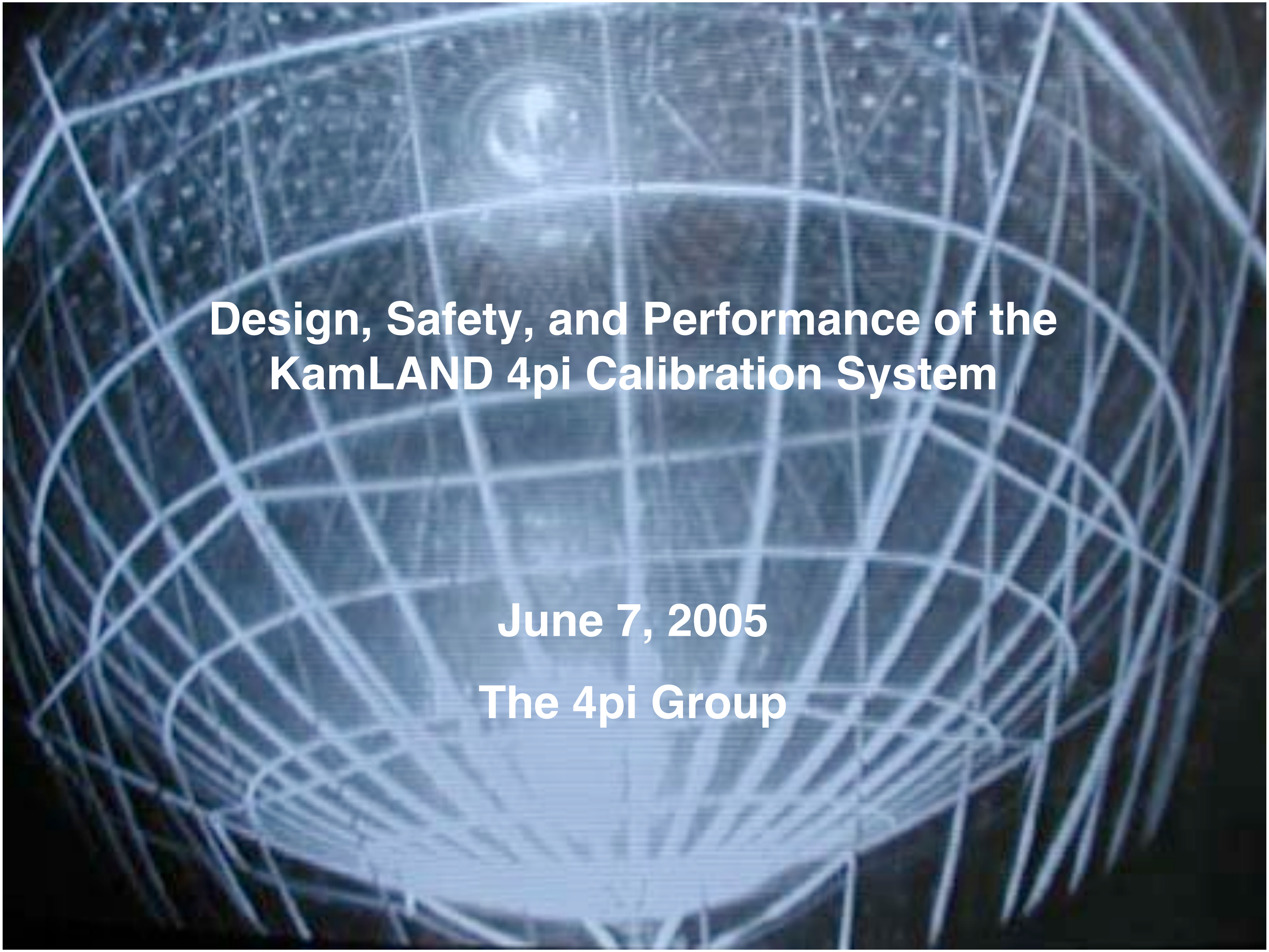


Design, Safety, and Performance of the KamLAND 4pi Calibration System

June 7, 2005

The 4pi Group

4π Group

S. Abbott
B. Berger
T. Classen
P. Decowski
D. Dwyer
A. Franck
S.J. Freedman
B. Fujikawa
M. Galloway
F. Gray
K.M. Heeger
G. Keefer
J. Meyer
J. Learned
K.-B. Luk
C. Mauger
Y. Minamihara
B. Perry
M. Rosen
H. Steiner
D. Syversryd
E. Yakoushev
T. Walker
J. Wallig
L. Winslow

http://kmheeger.lbl.gov/kamland/4pi/

And they made it work…

Don Syversrud
Joe Wallig
Bruce Berger
Patrick Decowski
Kengo Nakamura

Charge of this Review

1. Is this system safe to operate and safe for the KamLAND detector?

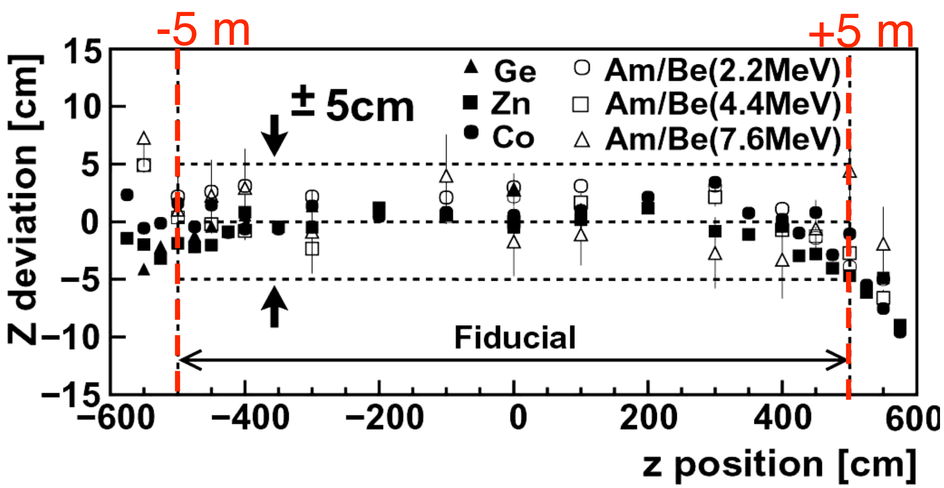
2. Can this system adequately perform the required calibrations?

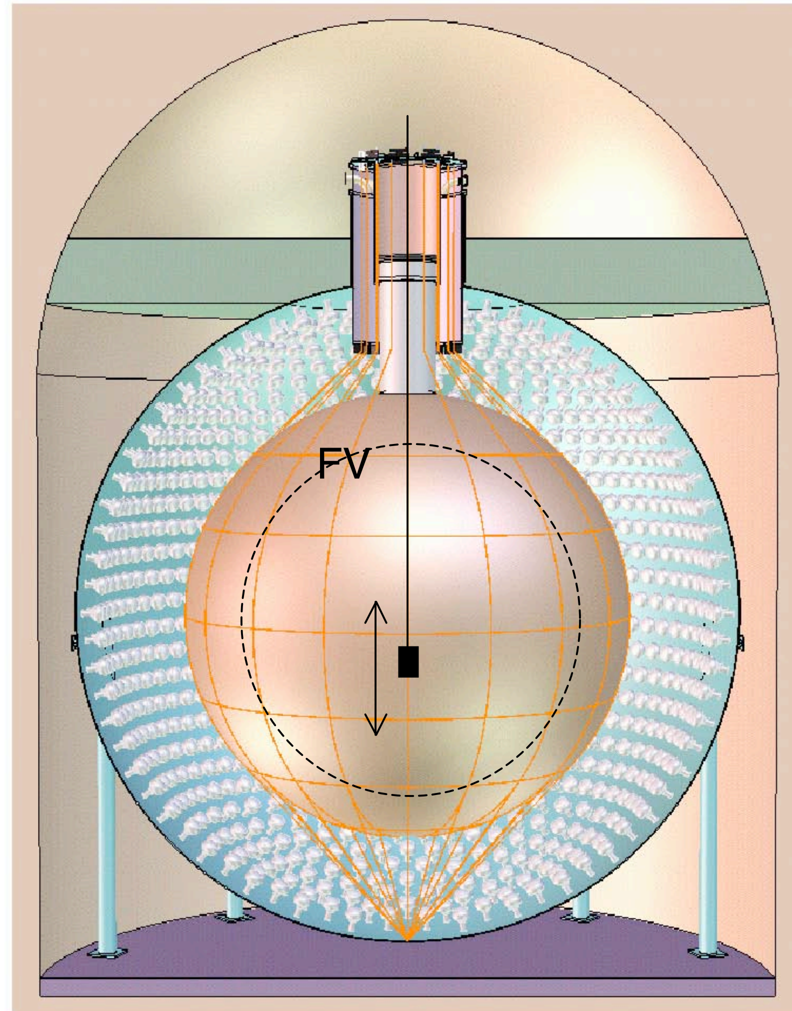
KamLAND z-axis Calibration

Routine Calibration Sources

^{68}Ge	e^+	2 x 0.511 MeV
^{65}Zn	γ	1.116 MeV
^{60}Co	γ	2.506 MeV
AmBe	γ, n	2.22, 4.44, and 7.65 MeV

Laser and LEDs





^{60}Co: 1.173+1.333 MeV in the detector

$\sigma = 6.2\% / \sqrt{E}$ light yield: 239 p.e./MeV

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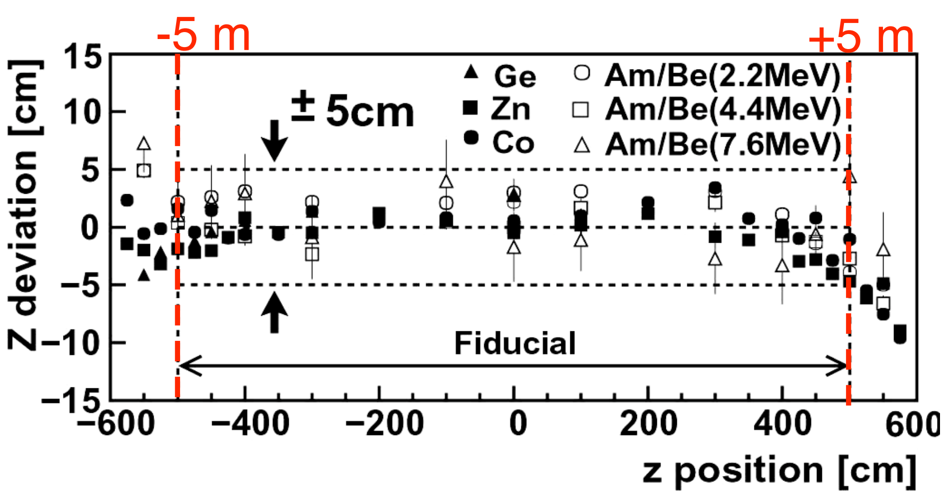

^{60}Co: 1.173+1.333 MeV in the detector

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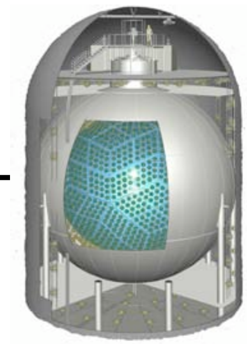
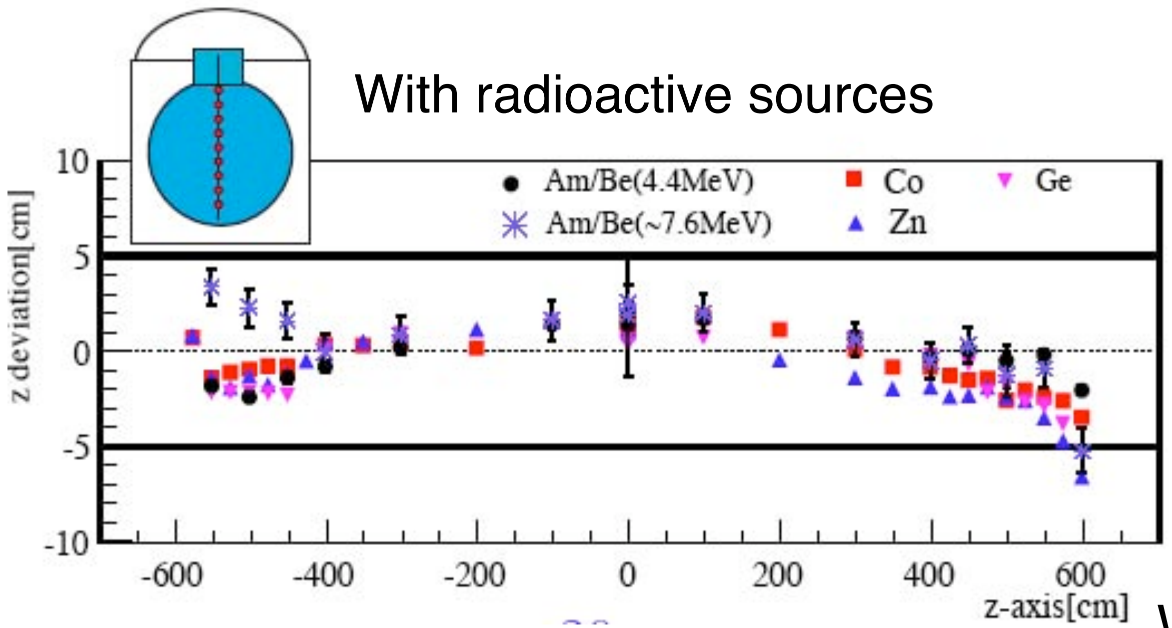
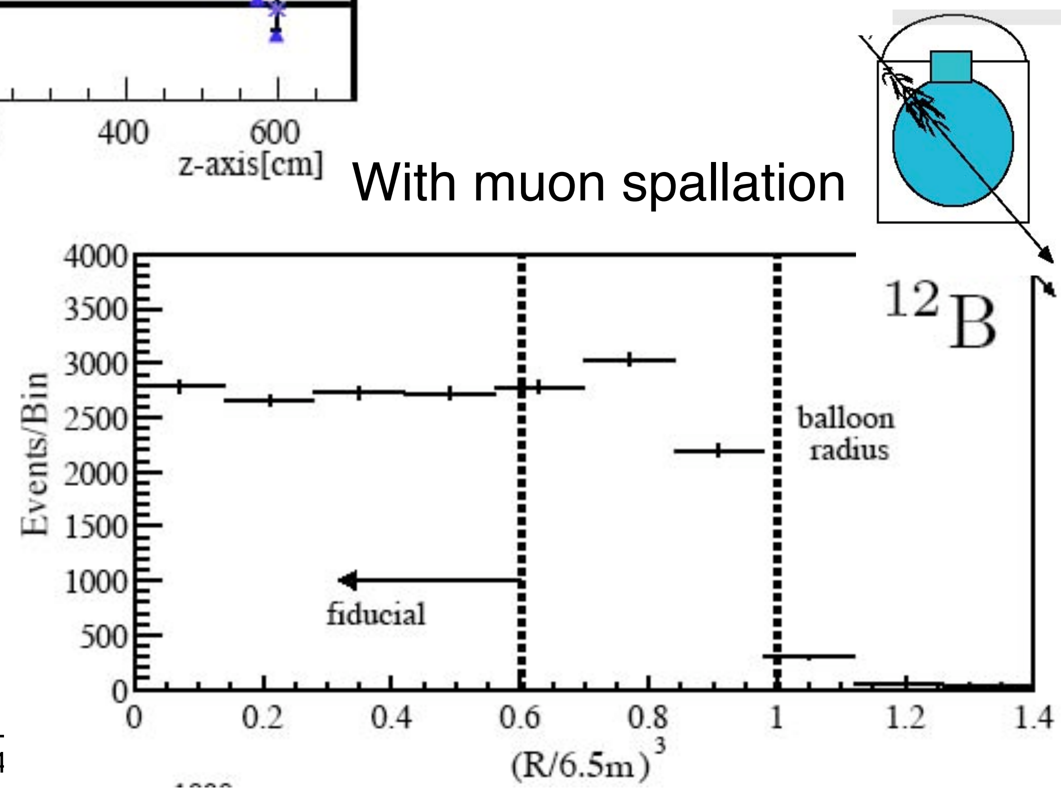
Fiducial Volume Determination



With radioactive sources



With muon spallation

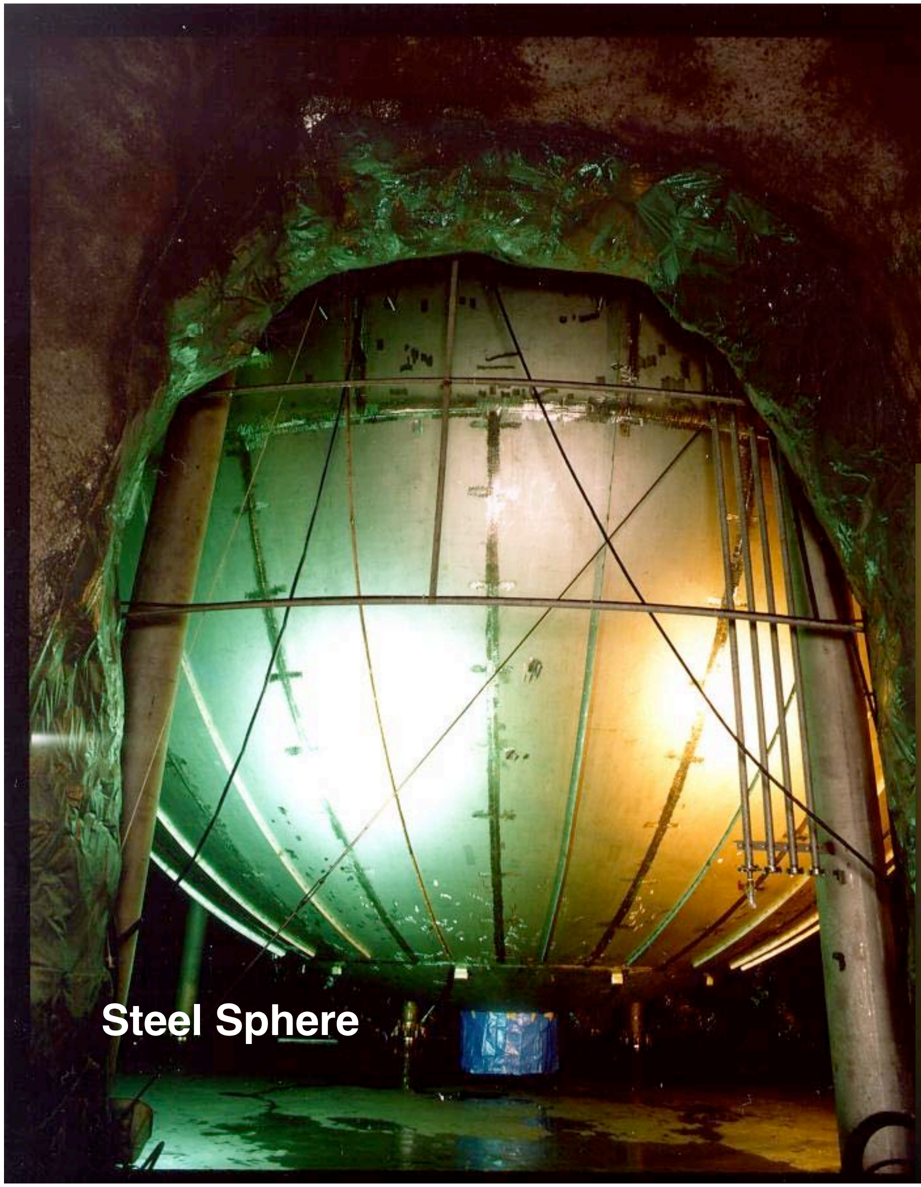


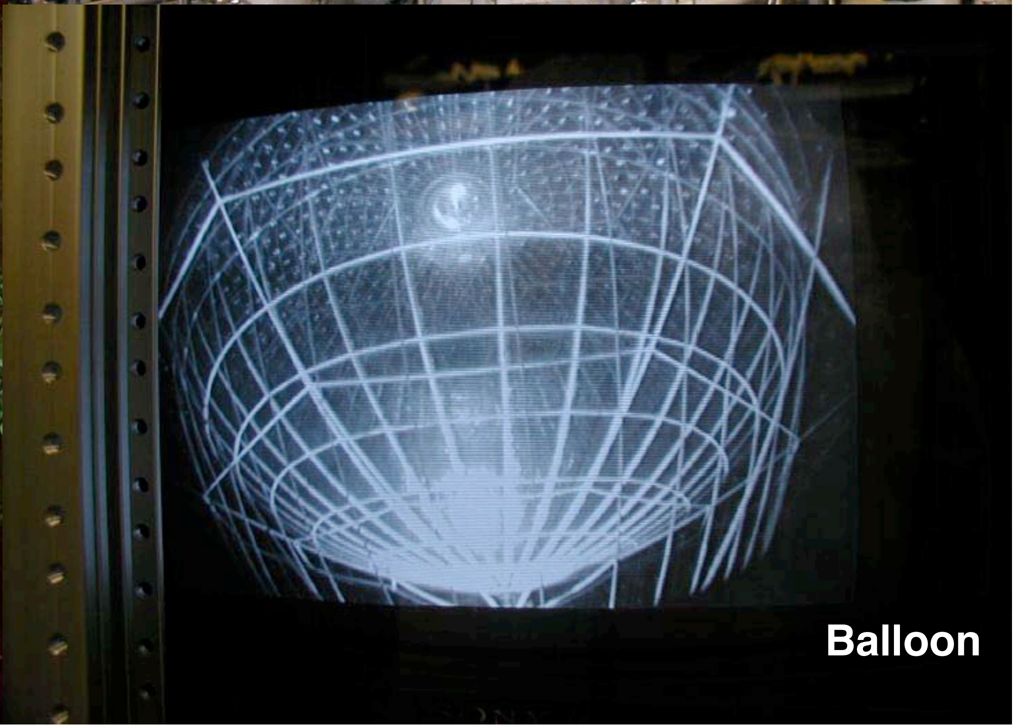
Fiducial/Total Volume Ratios

Geometrical	0.595 ± 0.013
^{12}B	0.607 ± 0.006
p(n,γ)d	0.587 ± 0.013
^{9}Li relative	< 2.7%

KamLAND volume error: 4.7%

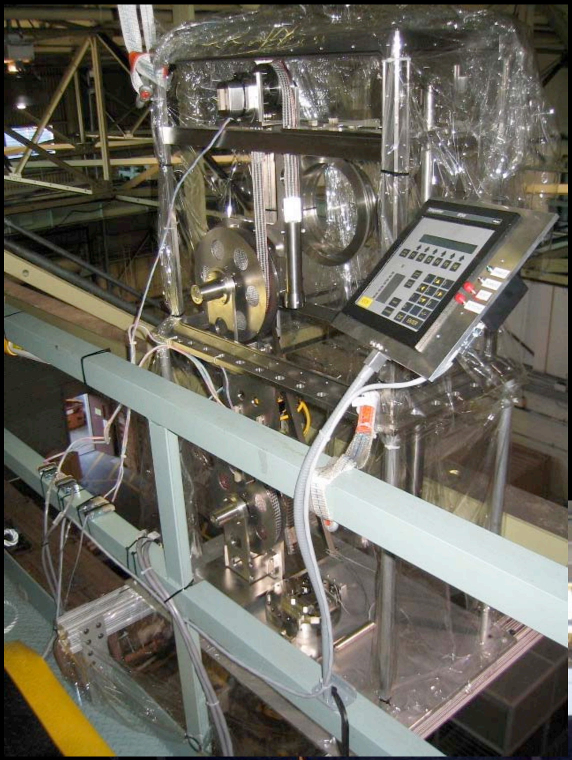
KamLAND





March 1, 2003
The “coat hanger” idea

September 16, 2004
Full test of deployment system

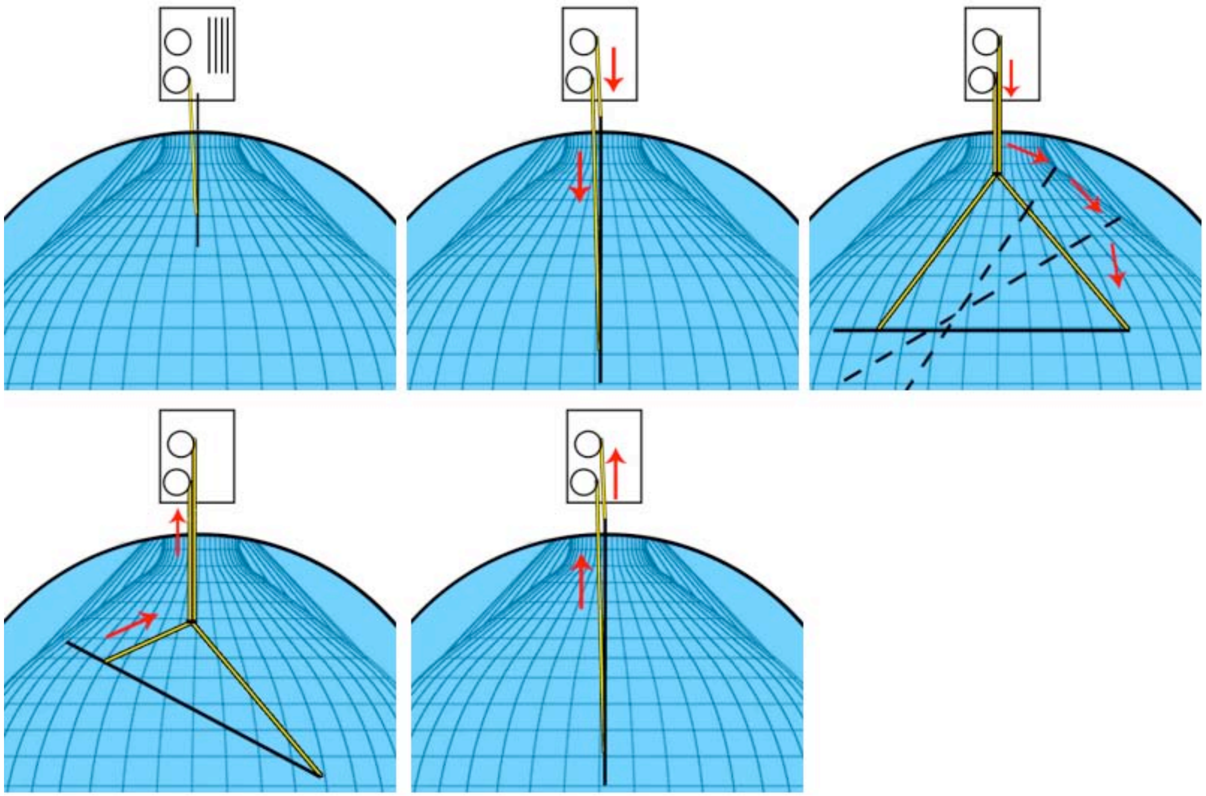


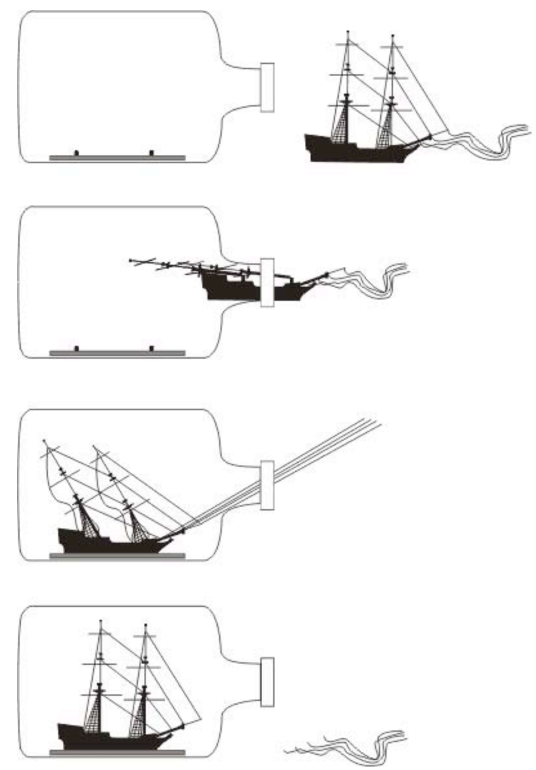
KamLAND Full-Volume Calibration

Calibration throughout entire detector volume

Fiducial volume: R < 5.5 m

$\Delta R_{FV} = 5$ cm $\rightarrow$ $\Delta V = 2.7\%$
$\Delta R_{FV} = 2$ cm $\rightarrow$ $\Delta V = 1.1\%$



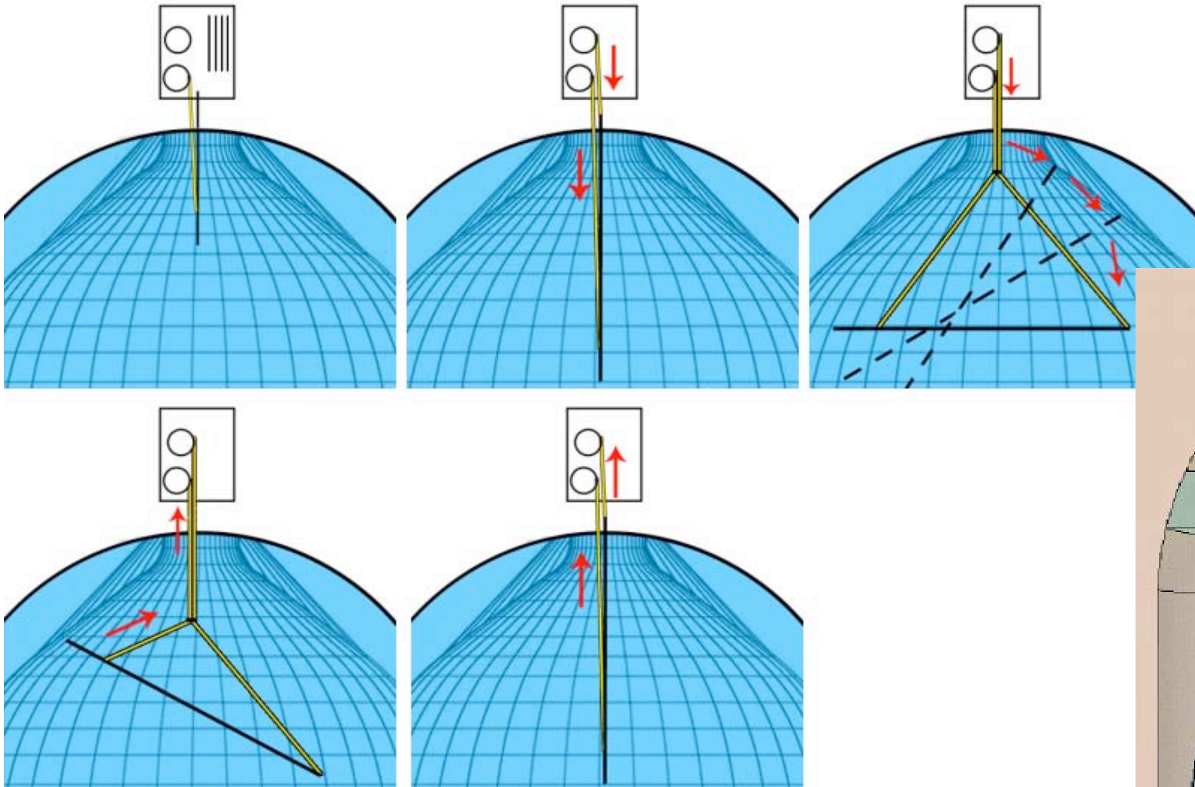


Position Dependence of Detector Response

Event energy	$E(r,\theta,\phi)$
Vertex reconstruction	$R_{fit}(r,\theta,\phi)$

KamLAND Full-Volume Calibration

Calibration throughout entire detector volume



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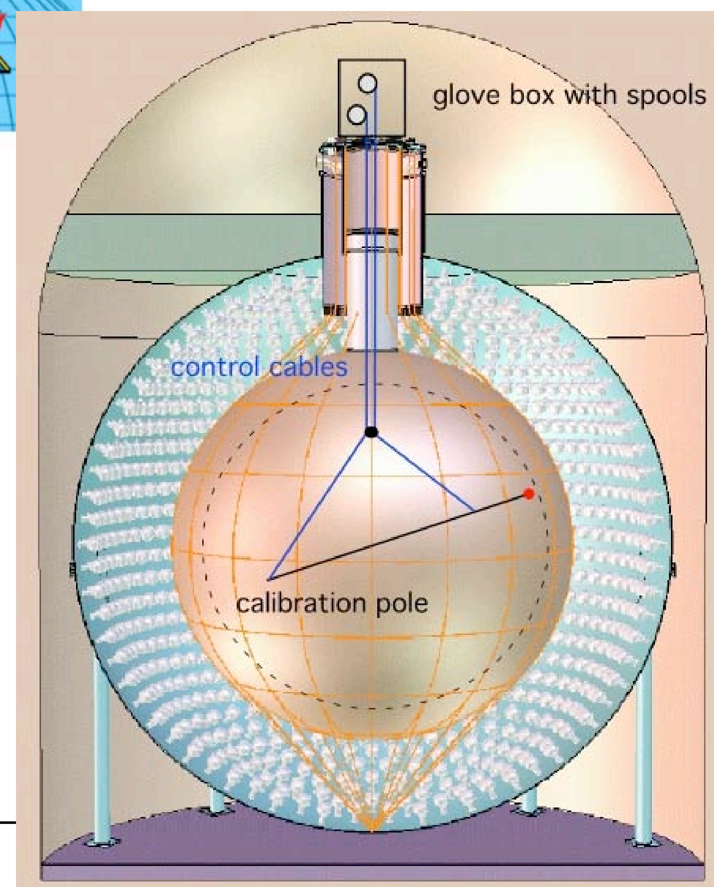


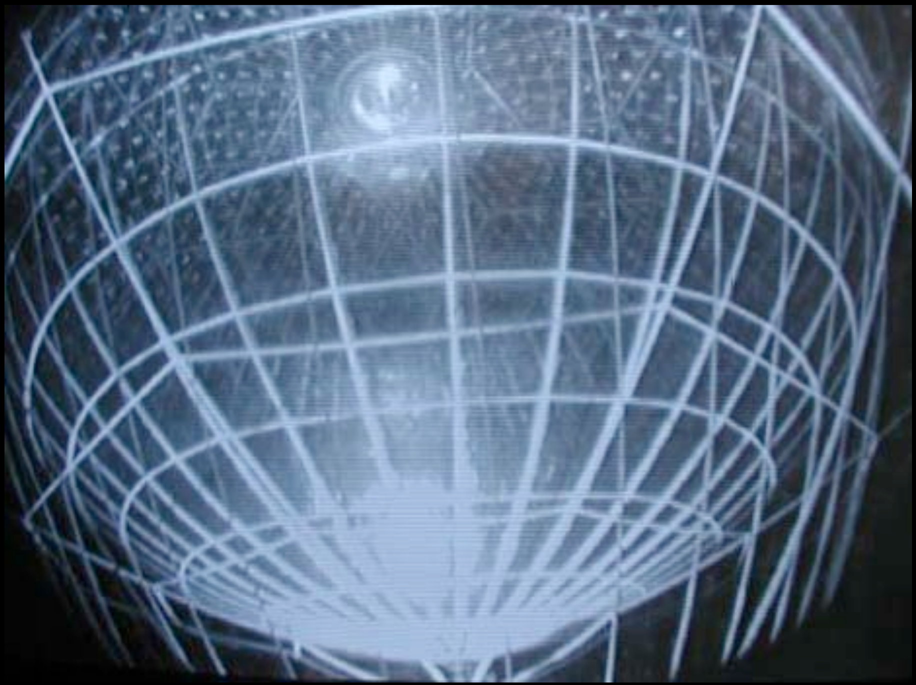
Position Dependence of Detector Response

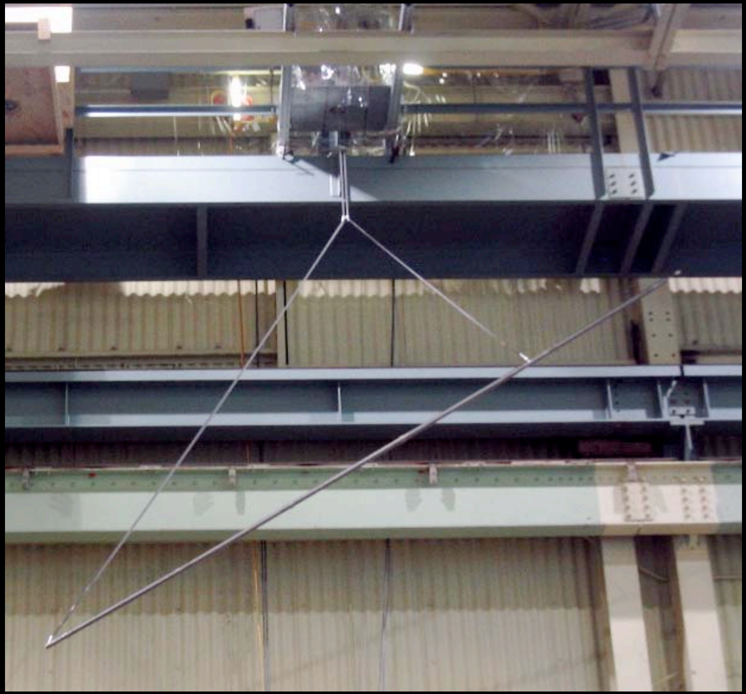
Event energy	$E(r,\theta,\phi)$
Vertex reconstruction	$R_{fit}(r,\theta,\phi)$

KamLAND Full-Volume Calibration System

Will reduce fiducial volume uncertainty:
4.7% → 1-1.5%.

Improves sensitivity to Δm^2_{12} (and θ_{12}).





Off-Axis Calibration System

I. Hardware

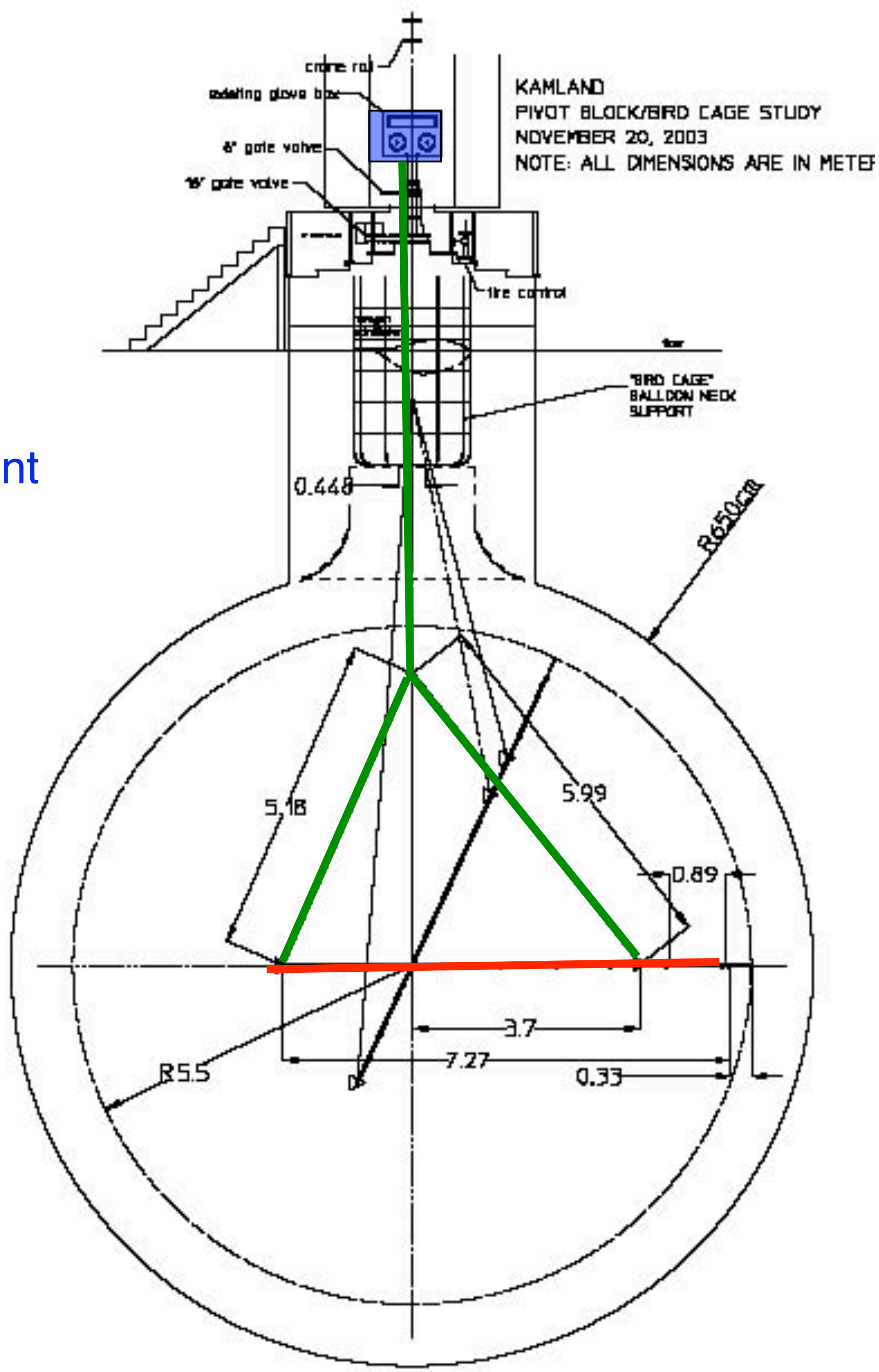
Glovebox System and Deployment Hardware

Control Cable + Pivot Block

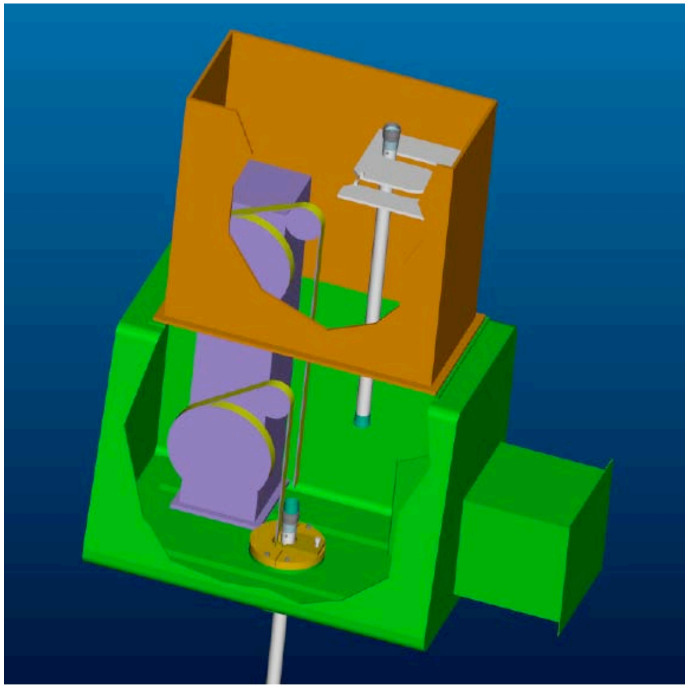
Calibration Pole

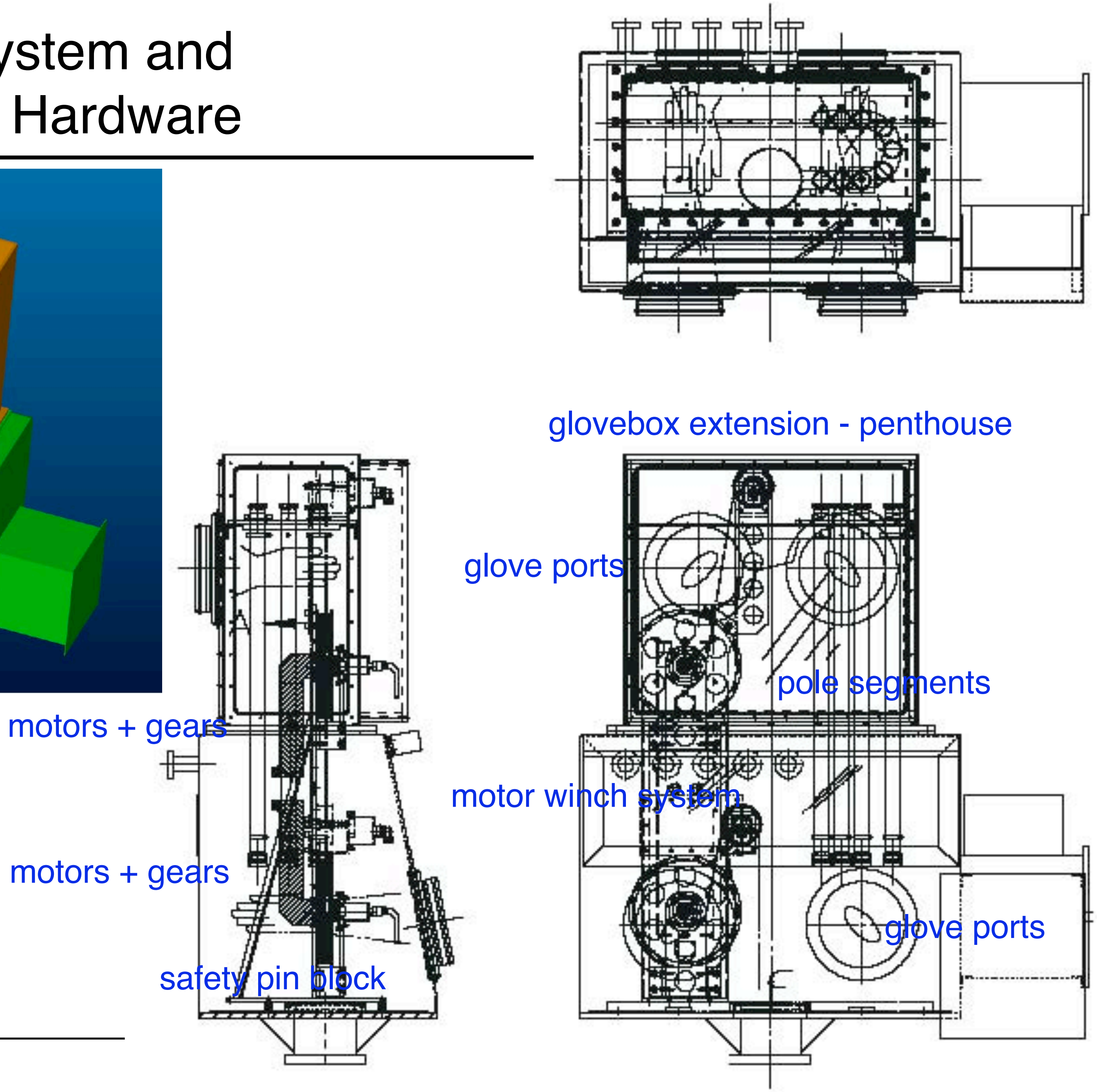
II. System Control Software

III. Position Reconstruction

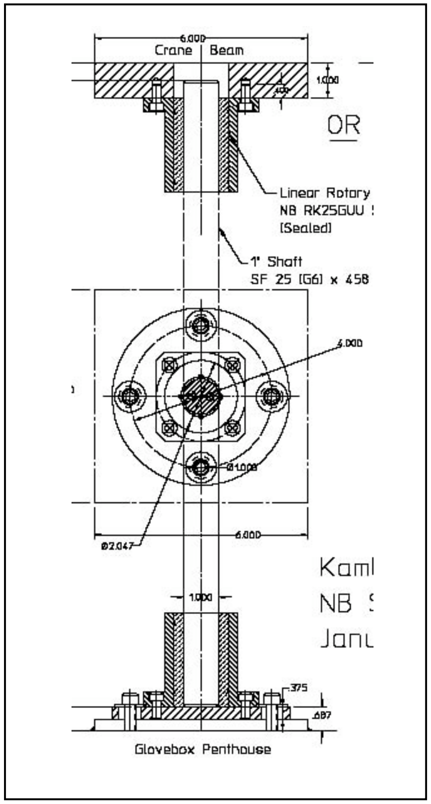


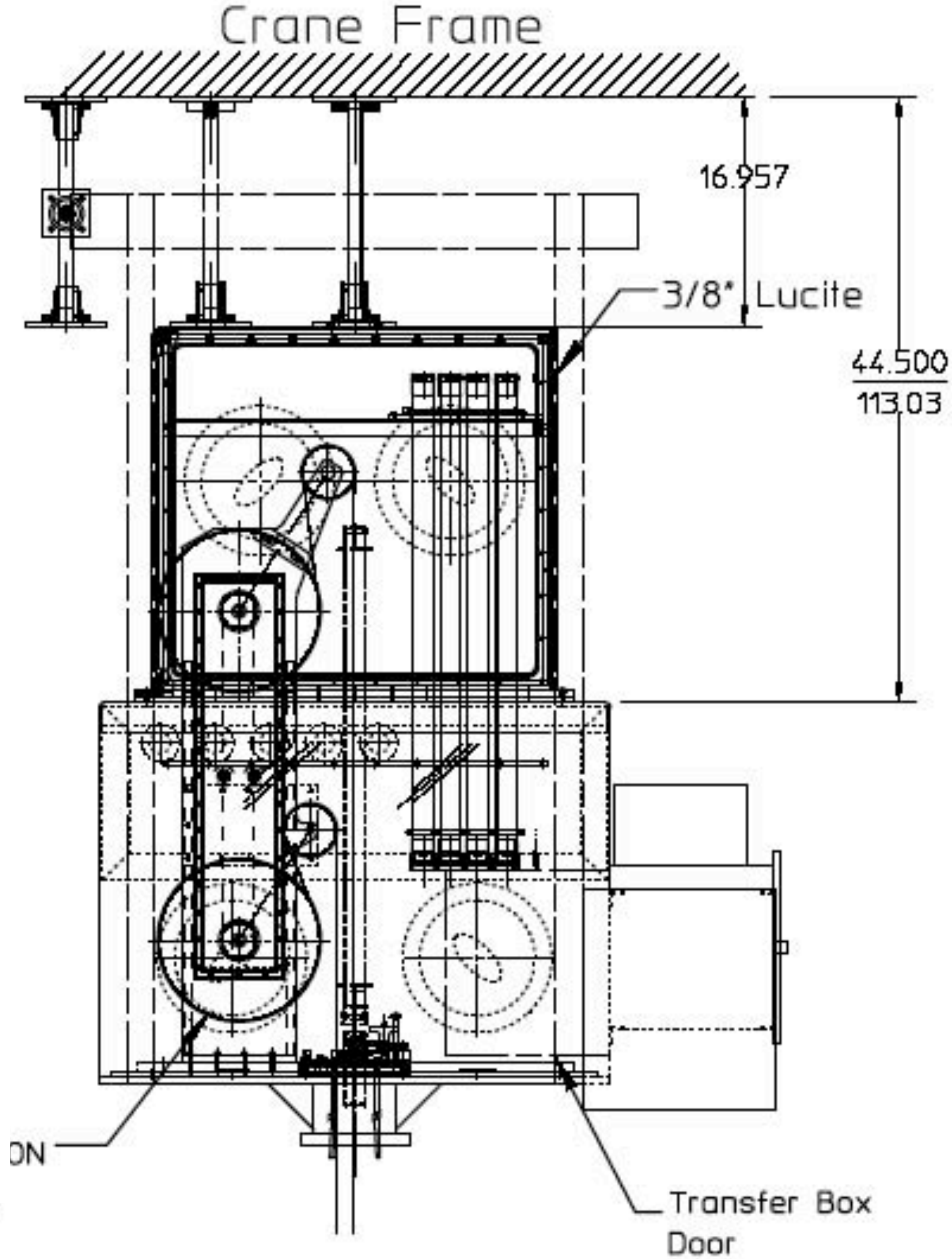
Glovebox System and Deployment Hardware





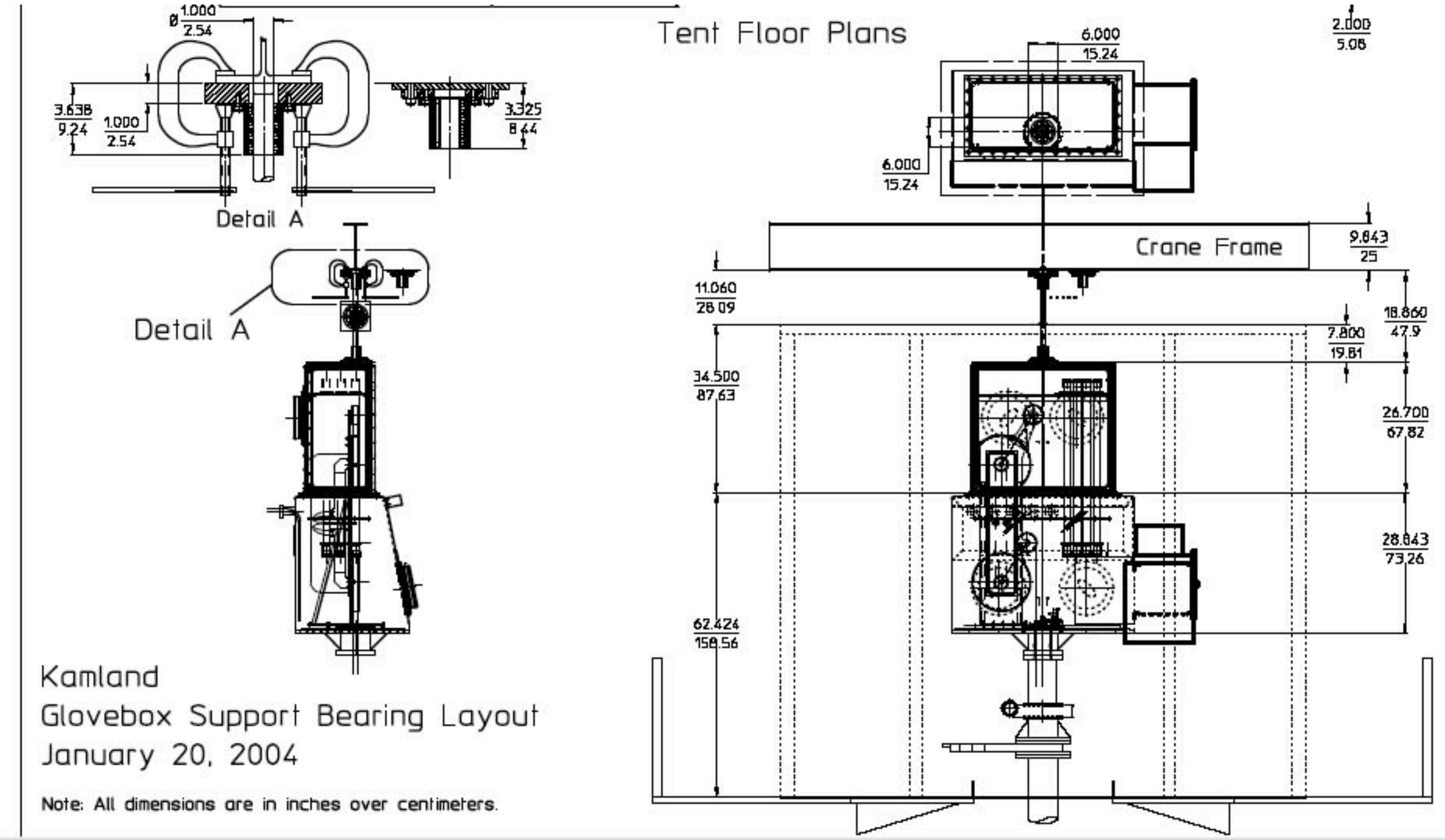
Glovebox Axial Support



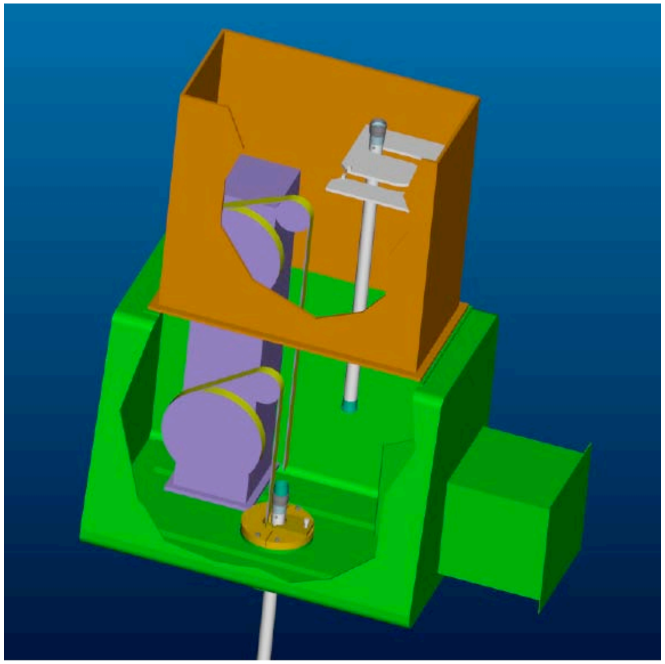


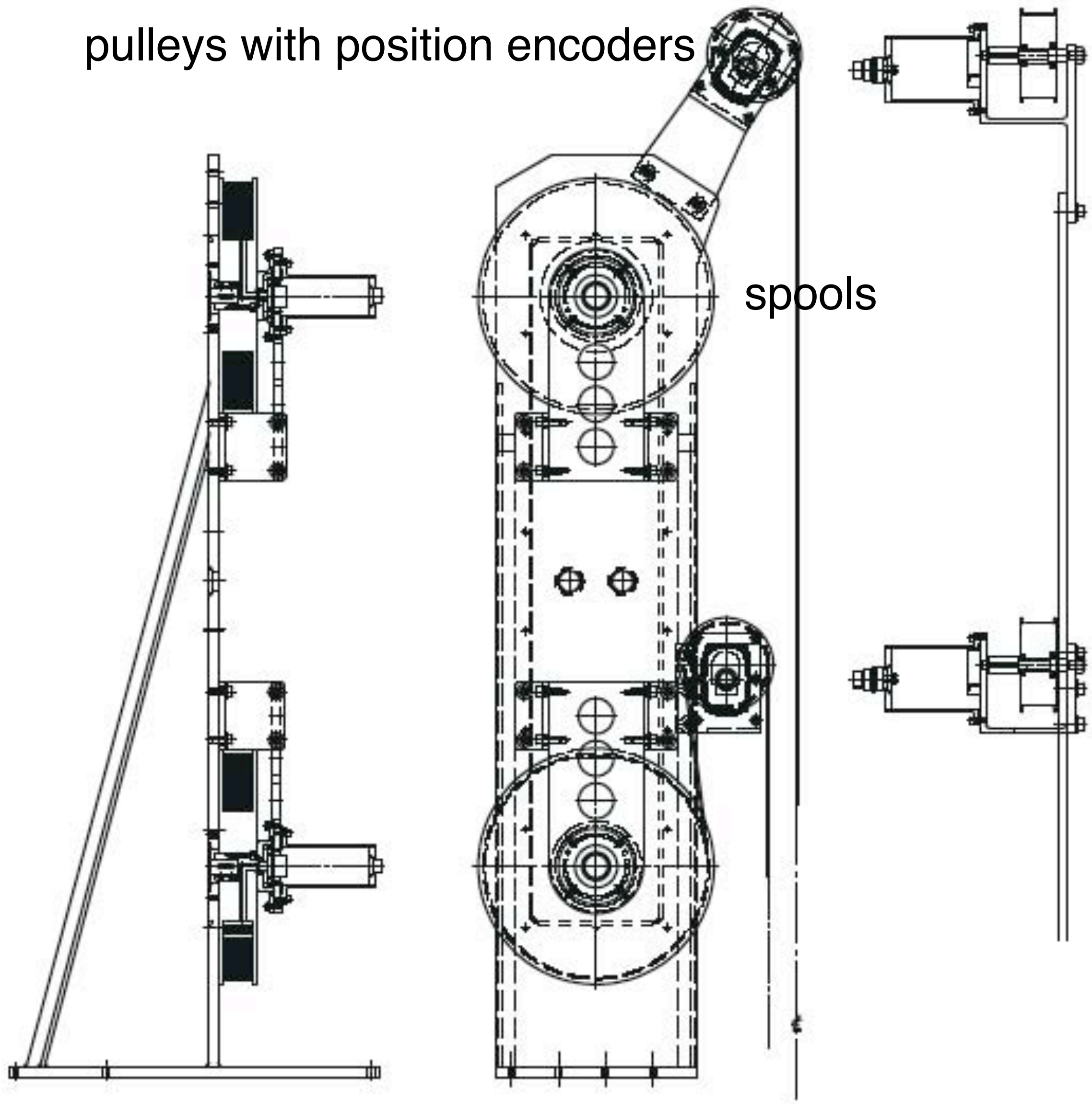
- provides axial stability
- allows system to rotate
- avoids future problems with rotary stage

Glovebox Axial Support

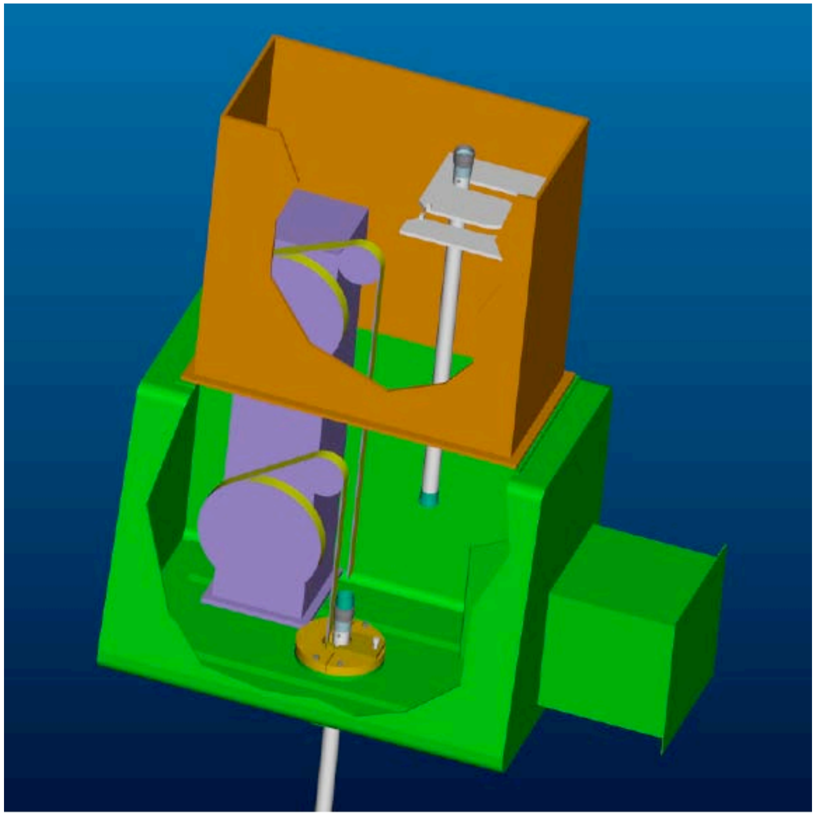


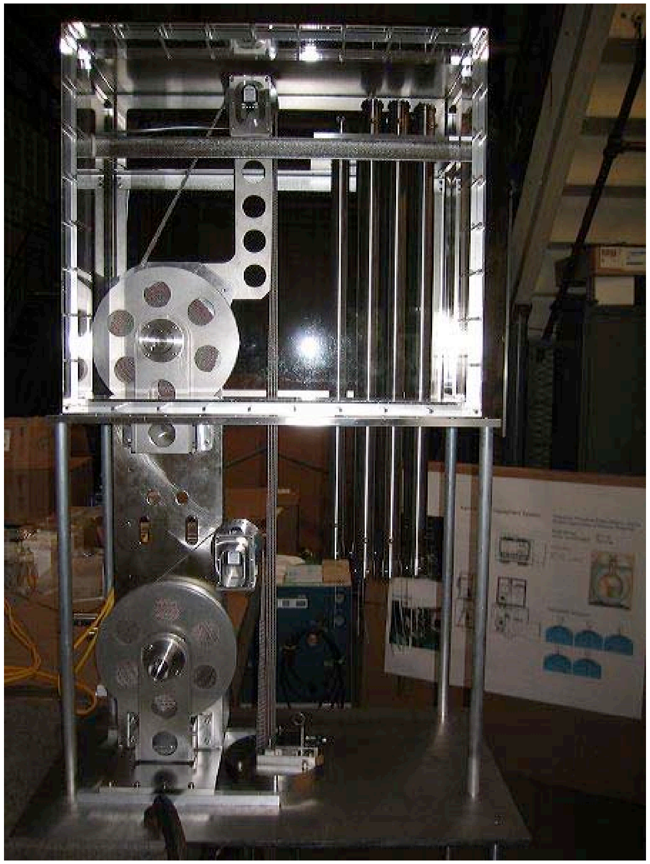
Motor Drive System



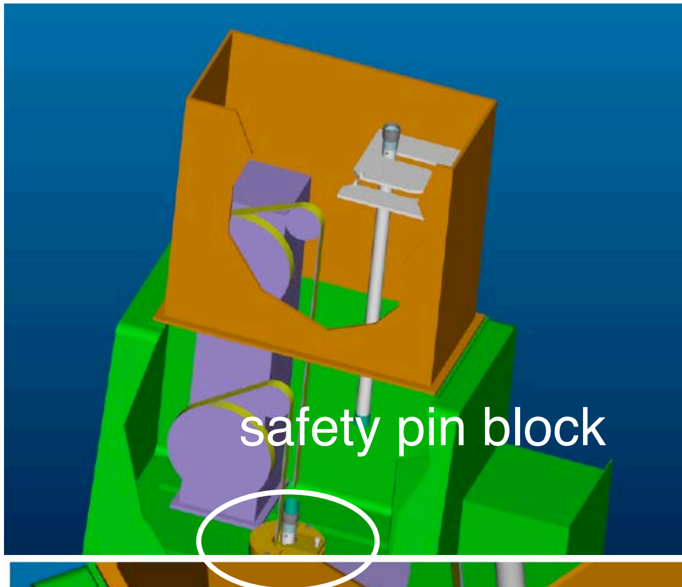


Glovebox System and Deployment Hardware



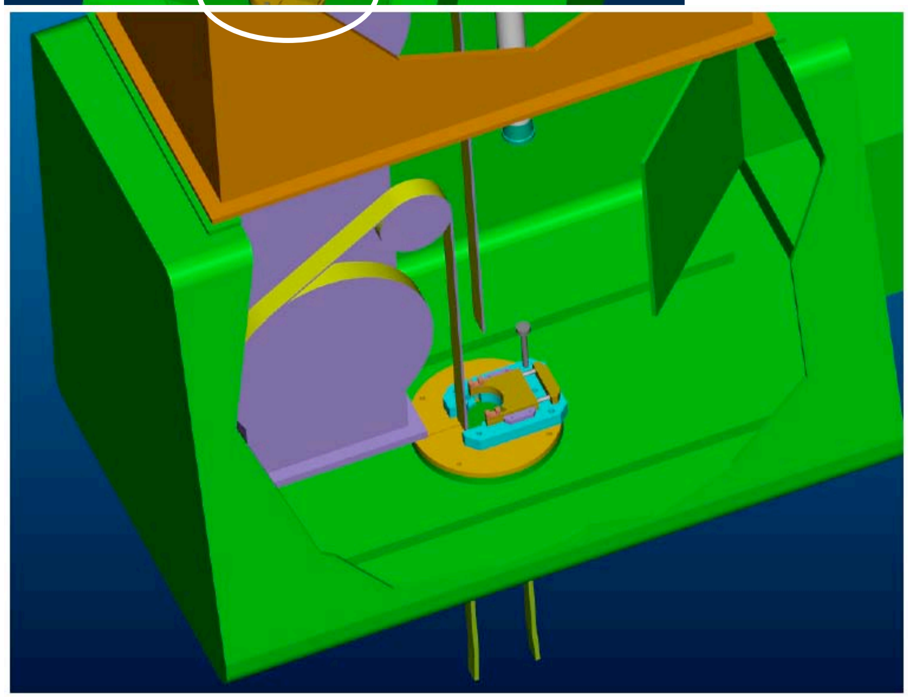


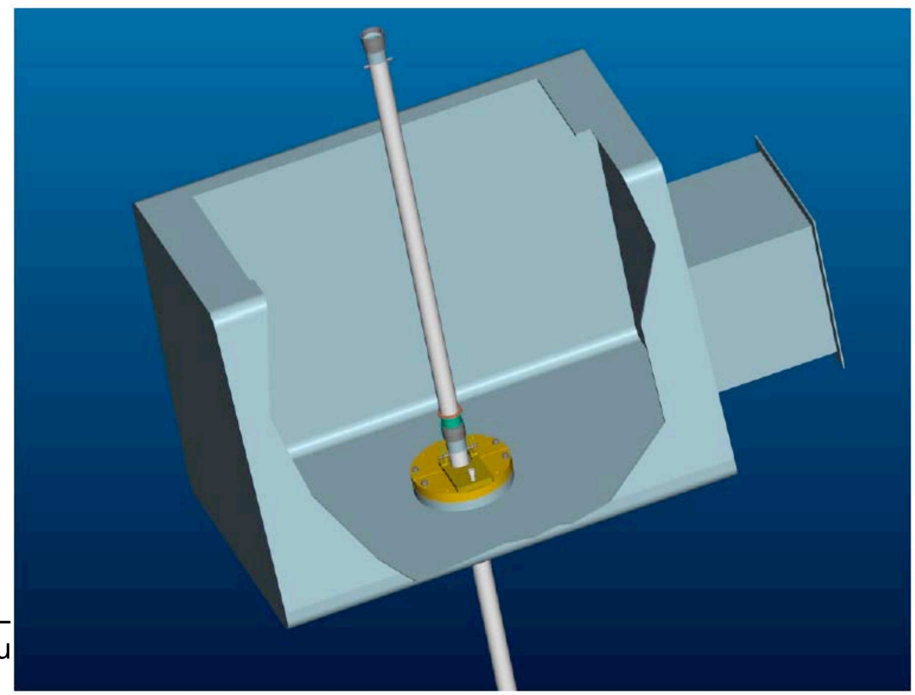
Safety Pin Block



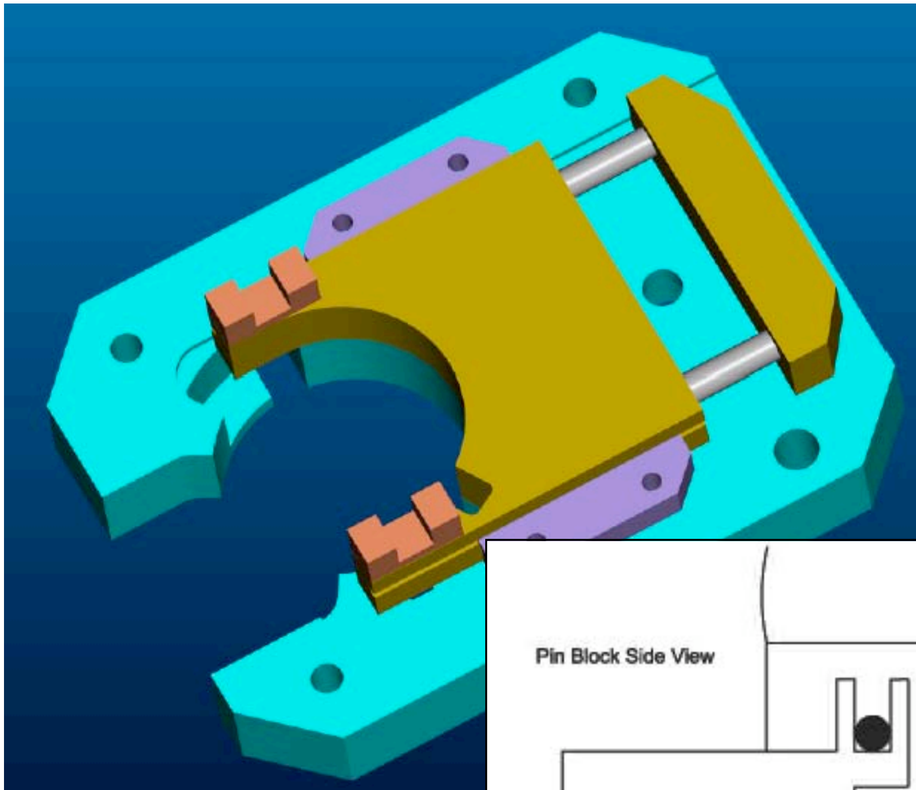
Purpose

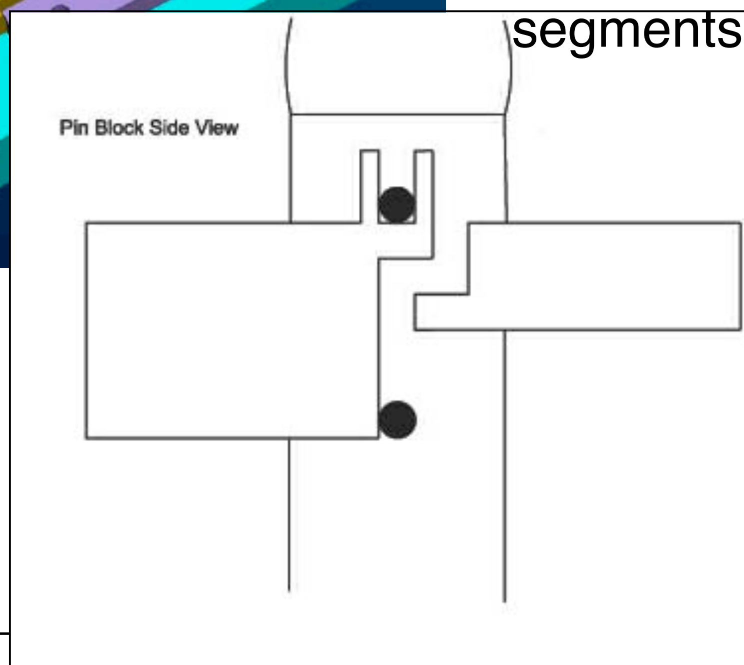
I. Safety block between glovebox and detector.
II. Used for assembly of pole.
III. Allows easy retrieval of pole.





Safety Pin Block





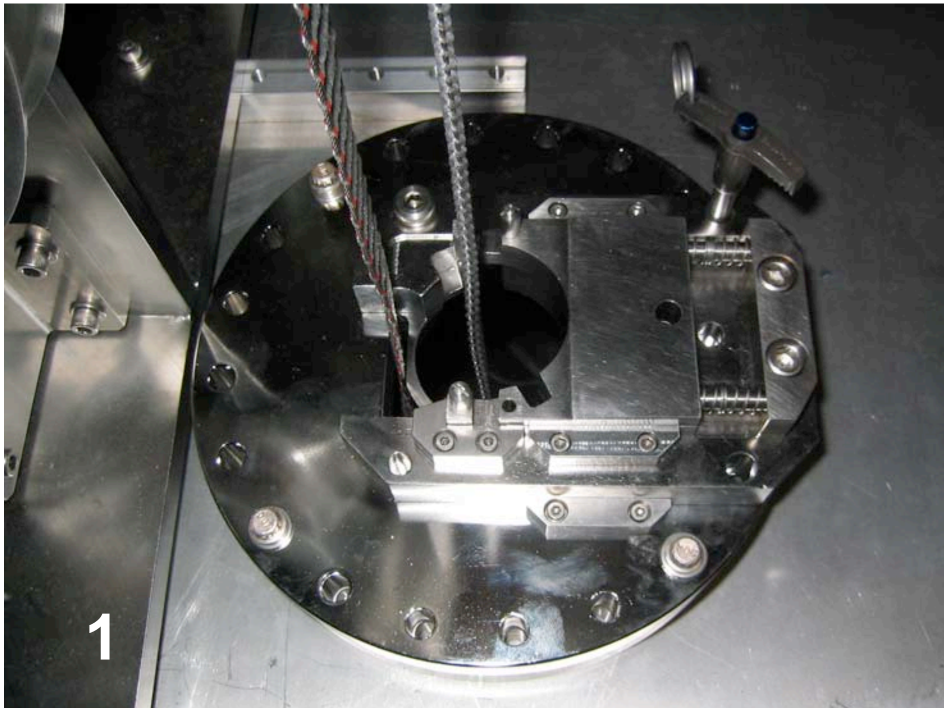
1. prevents pole segments from dropping into detector

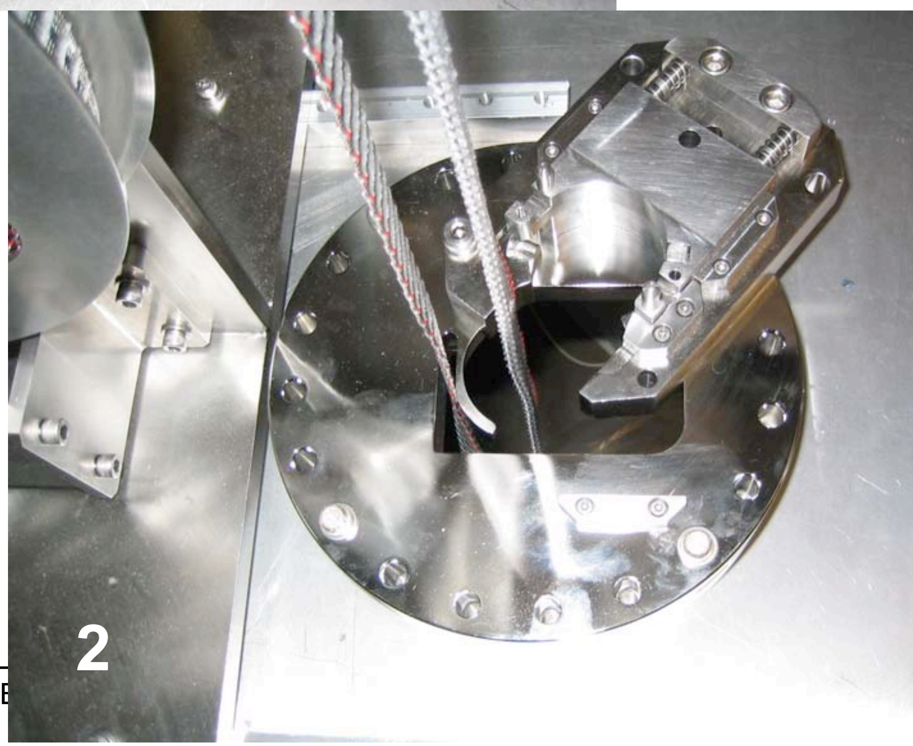
2. operator needs to turn pole segment when engaged in safety pin block

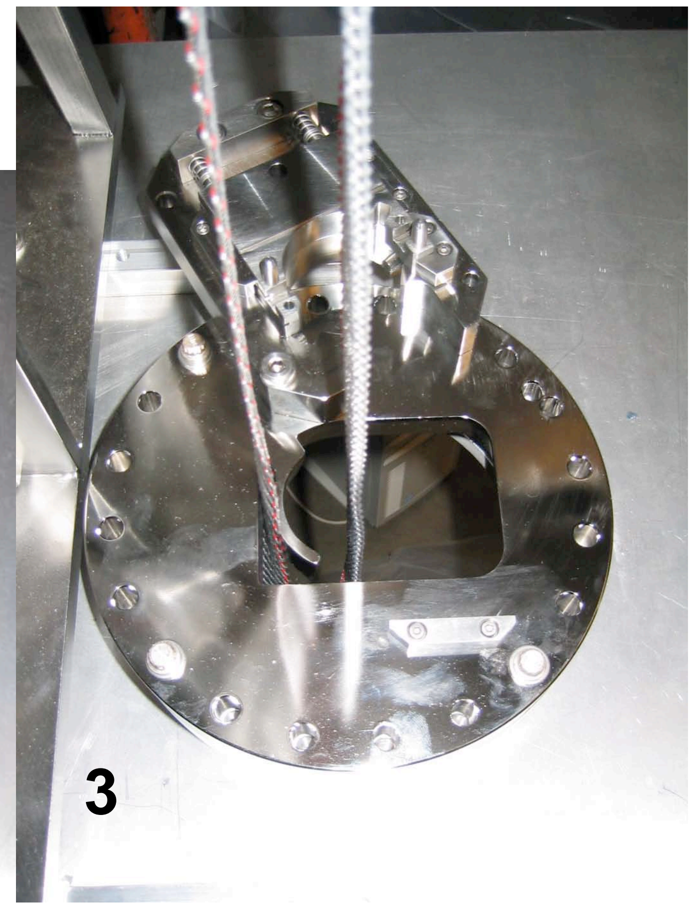
3. sliding block allows easy retrieval of calibration pole segments

The Pin Block

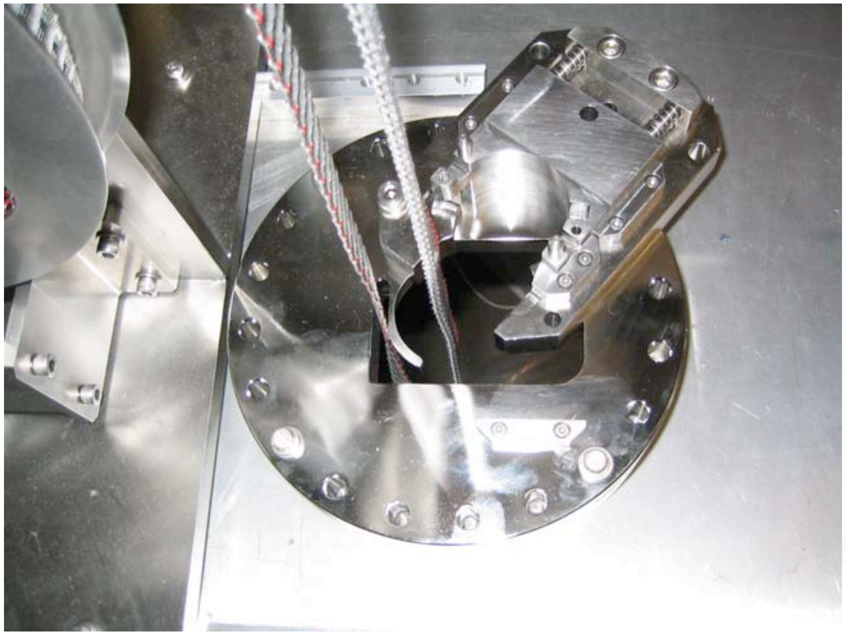
- mounted on conflat flange
- guides control cables
- rotates to allow pivot block to pass
- provides 3-step safety lock

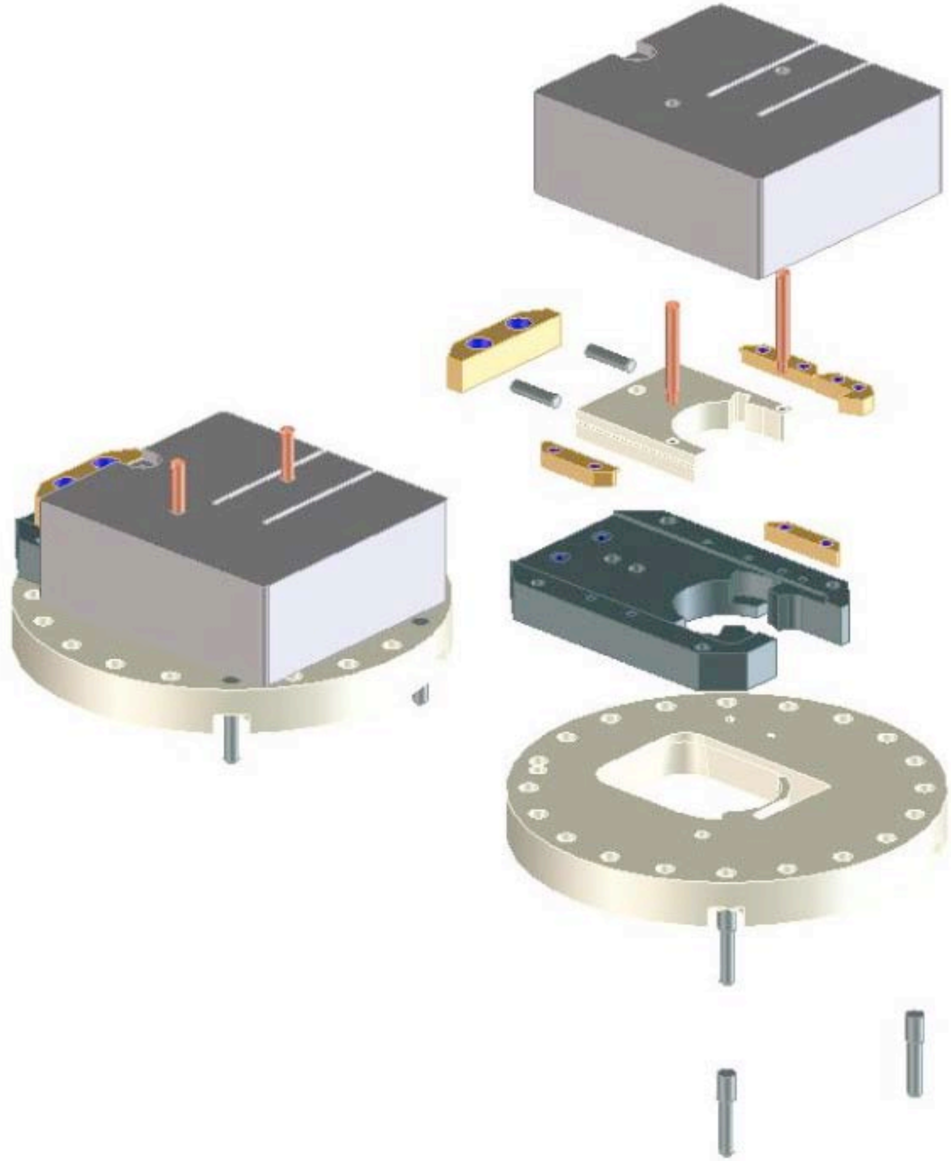


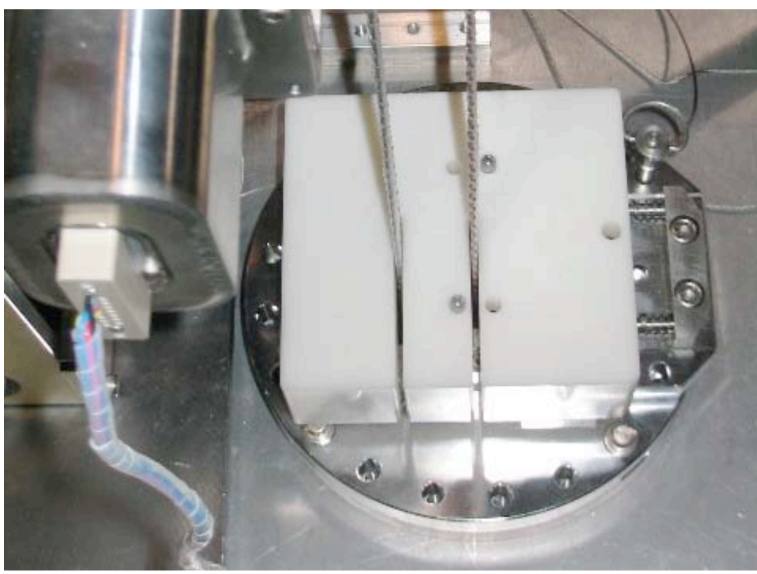


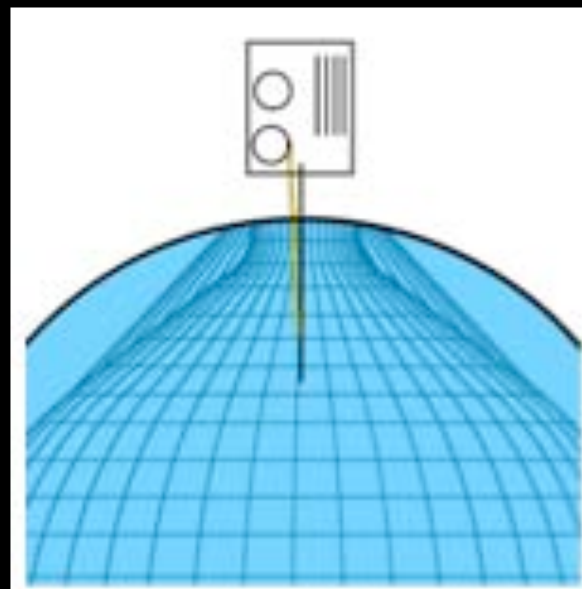


Pin Block Assembly

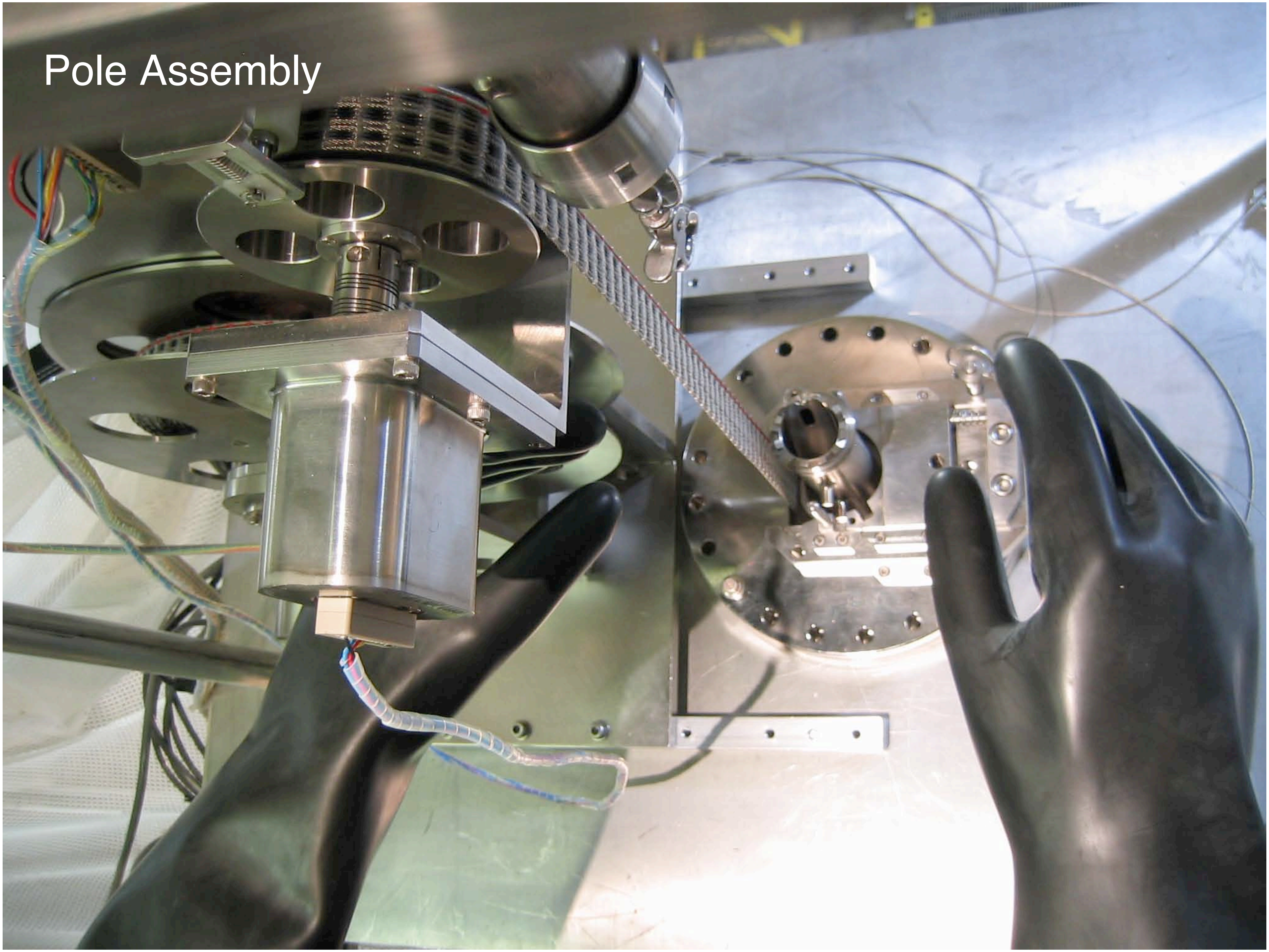


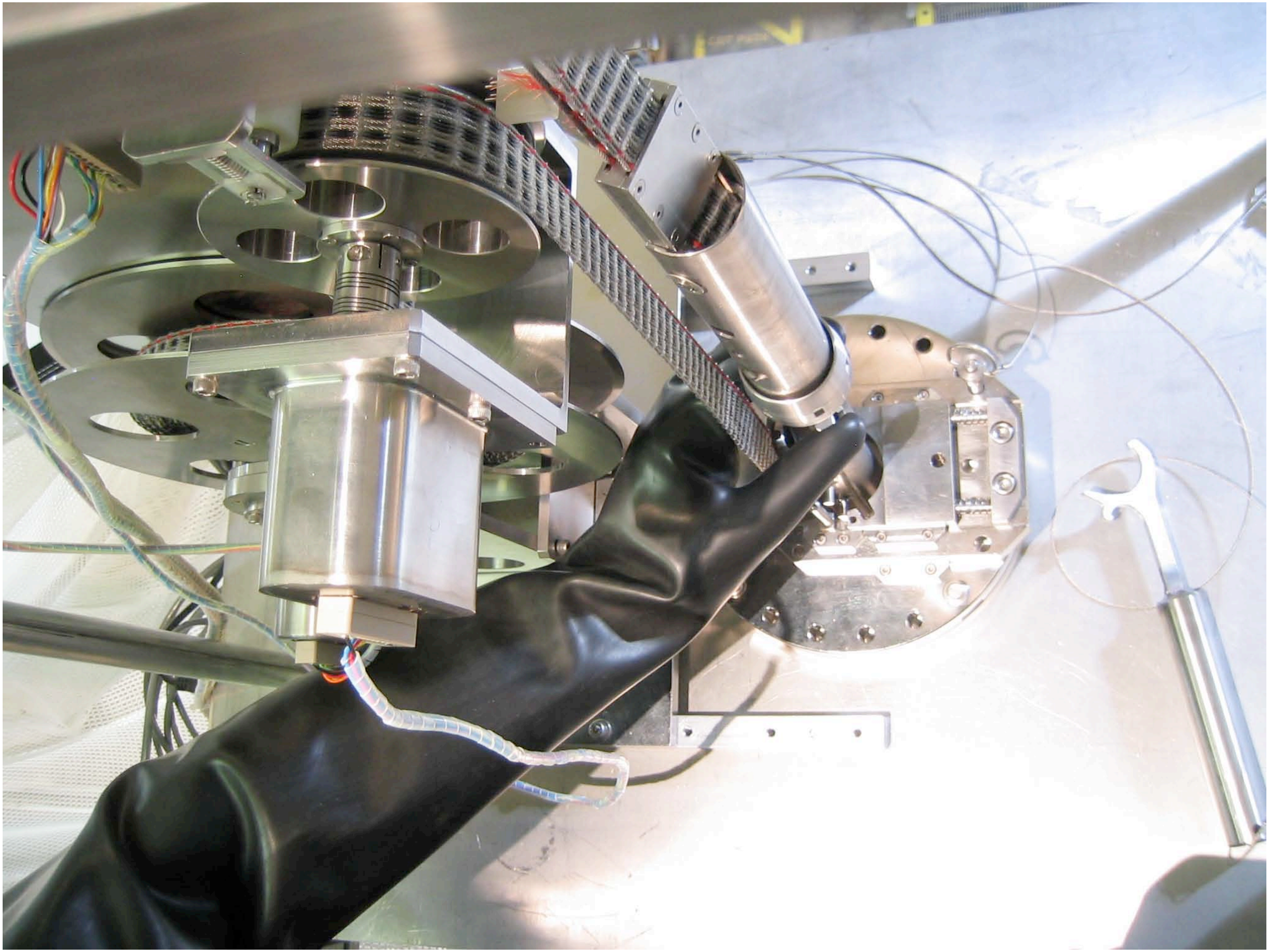


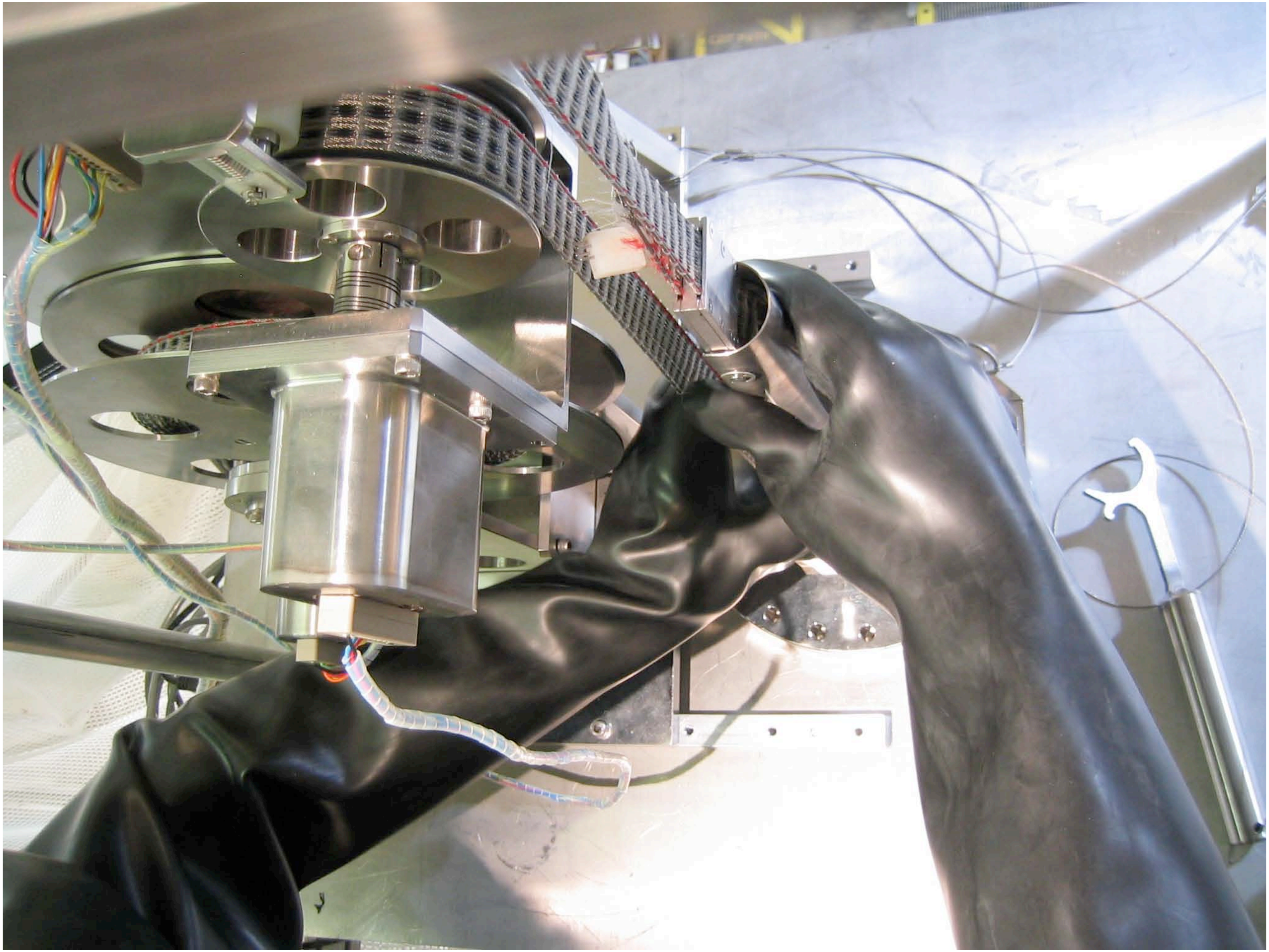


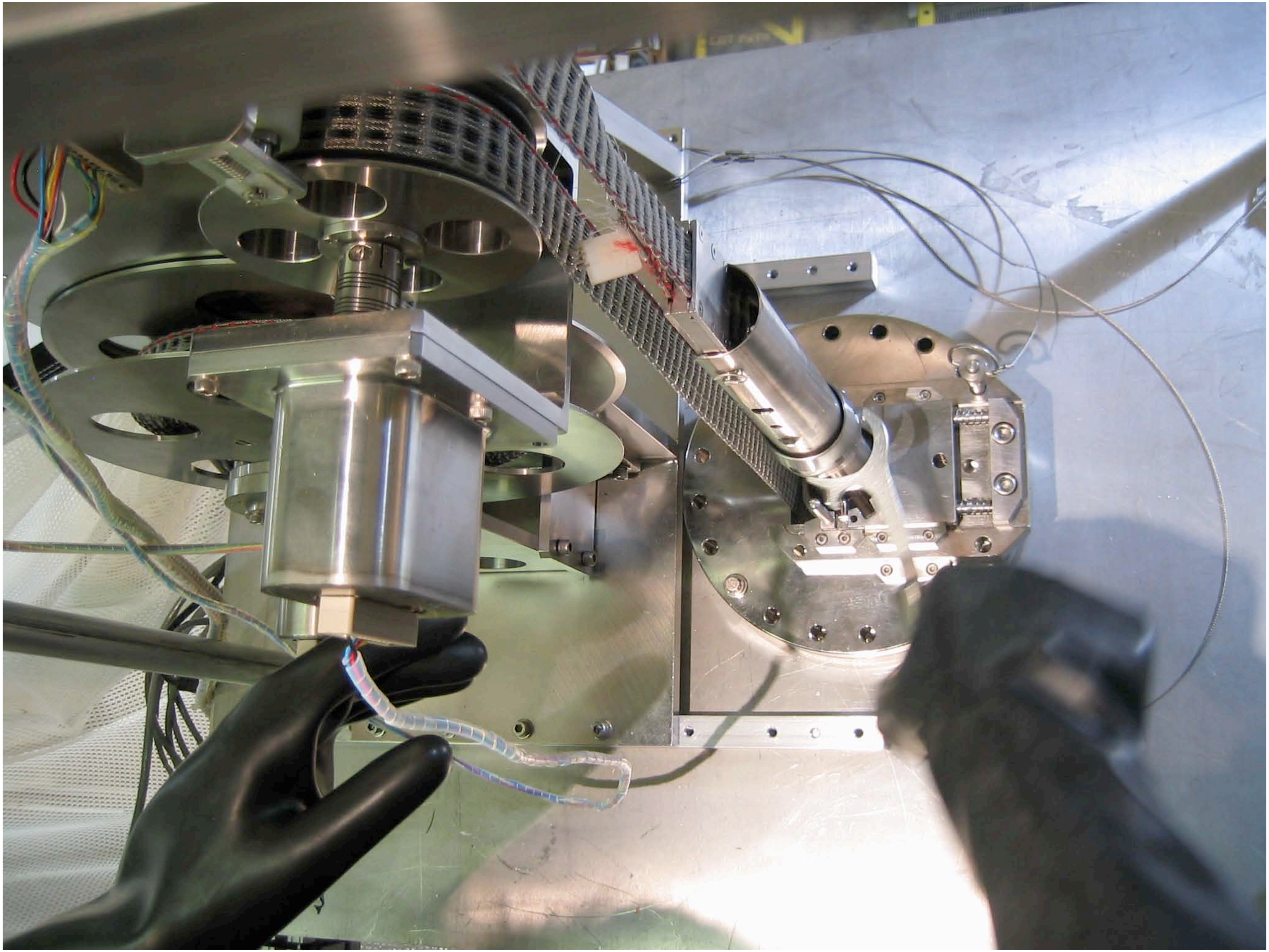


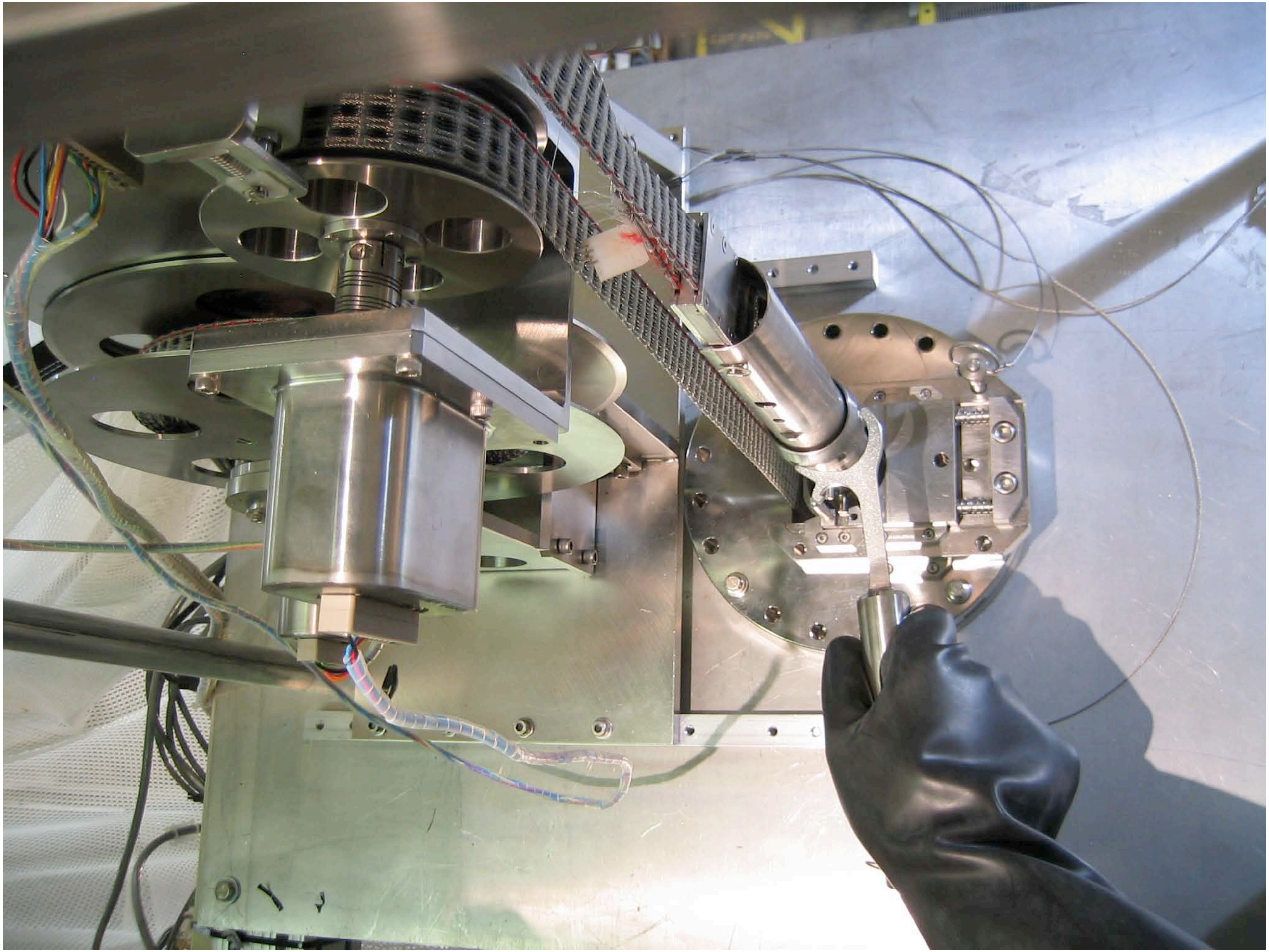
Assembly and Deployment

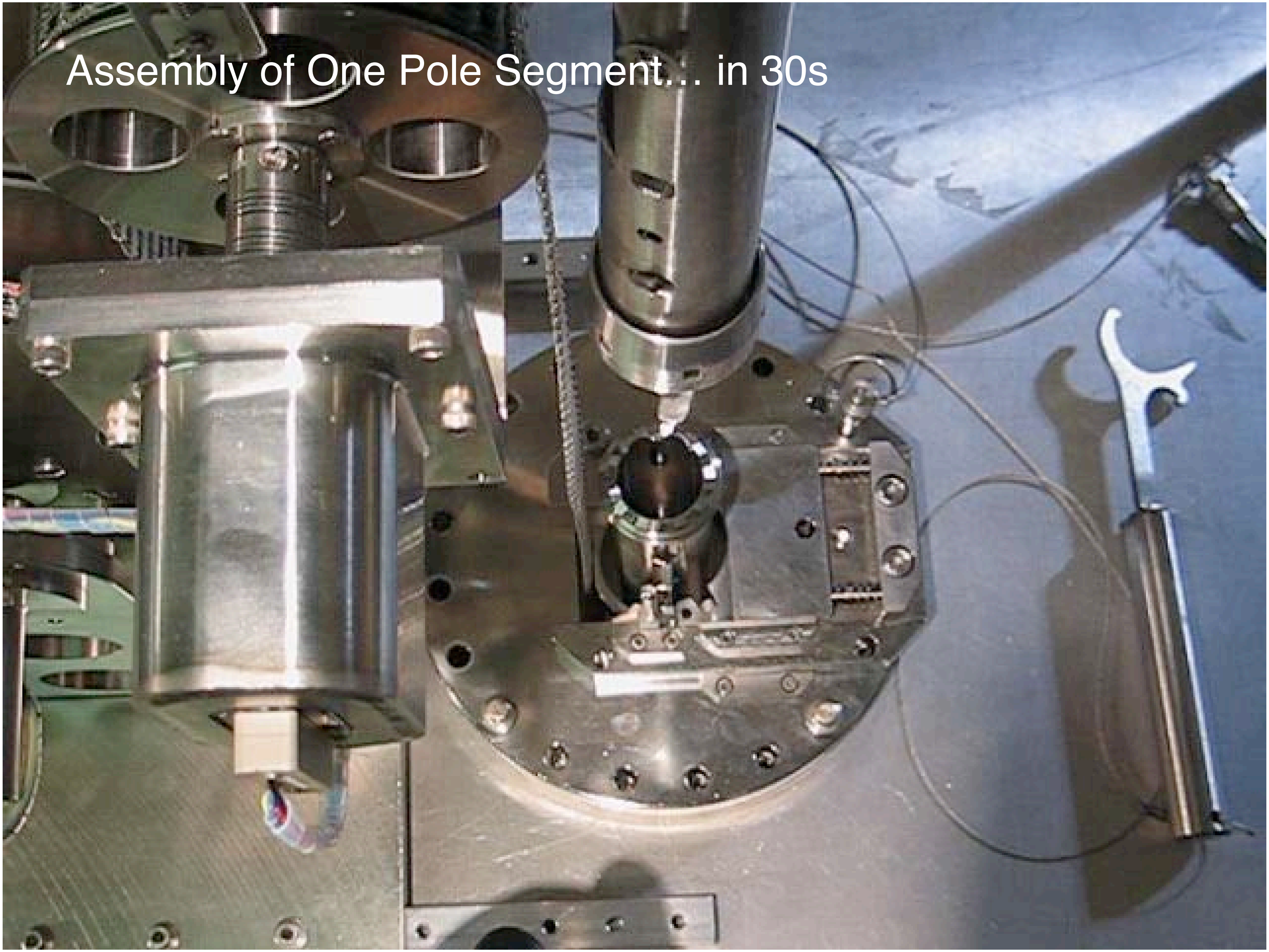

Pole Assembly



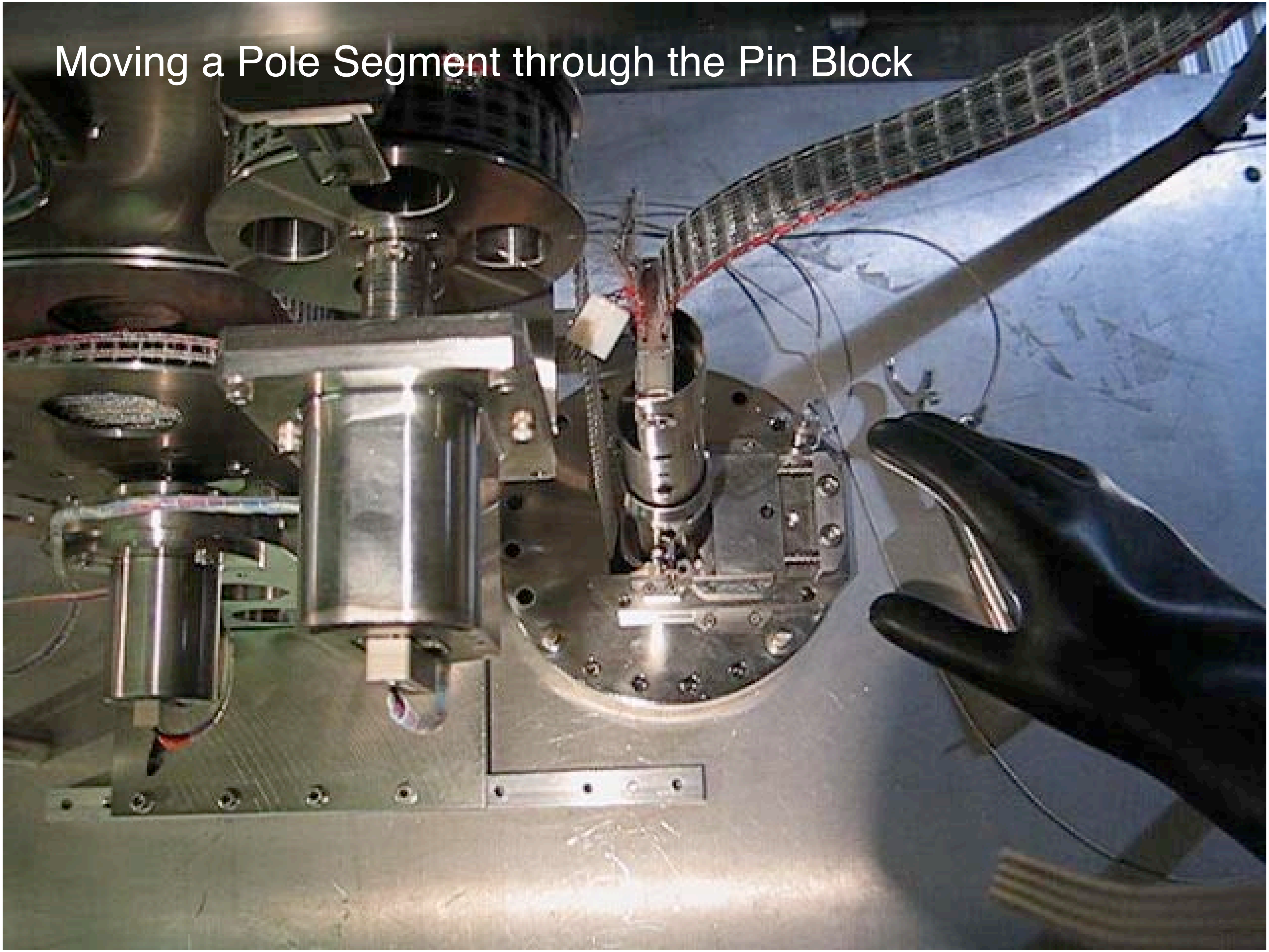




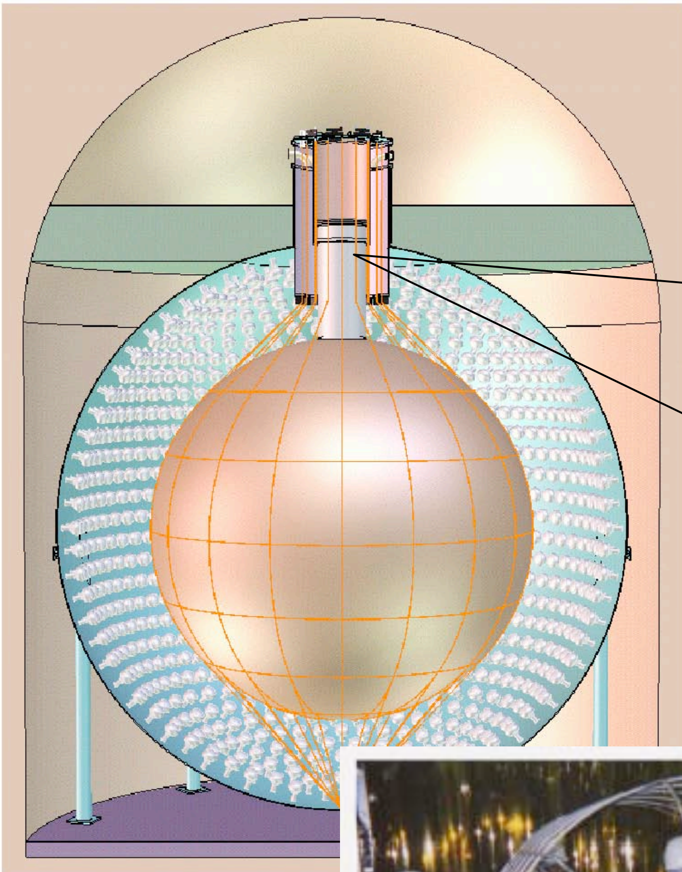


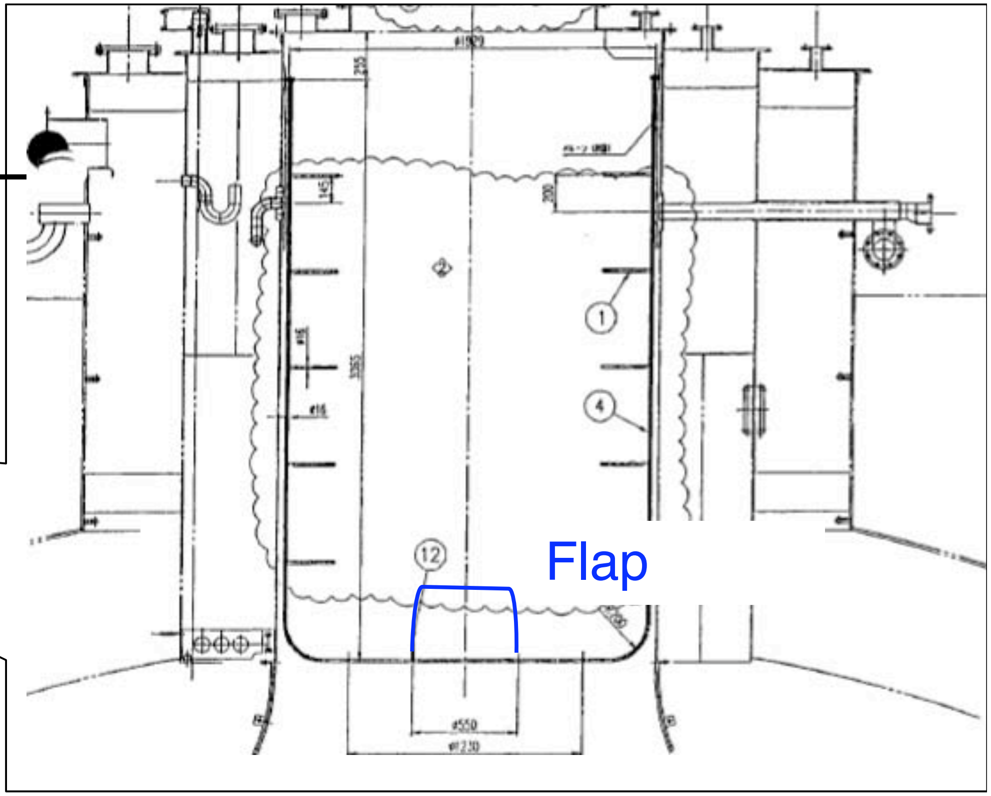

Assembly of One Pole Segment… in 30s

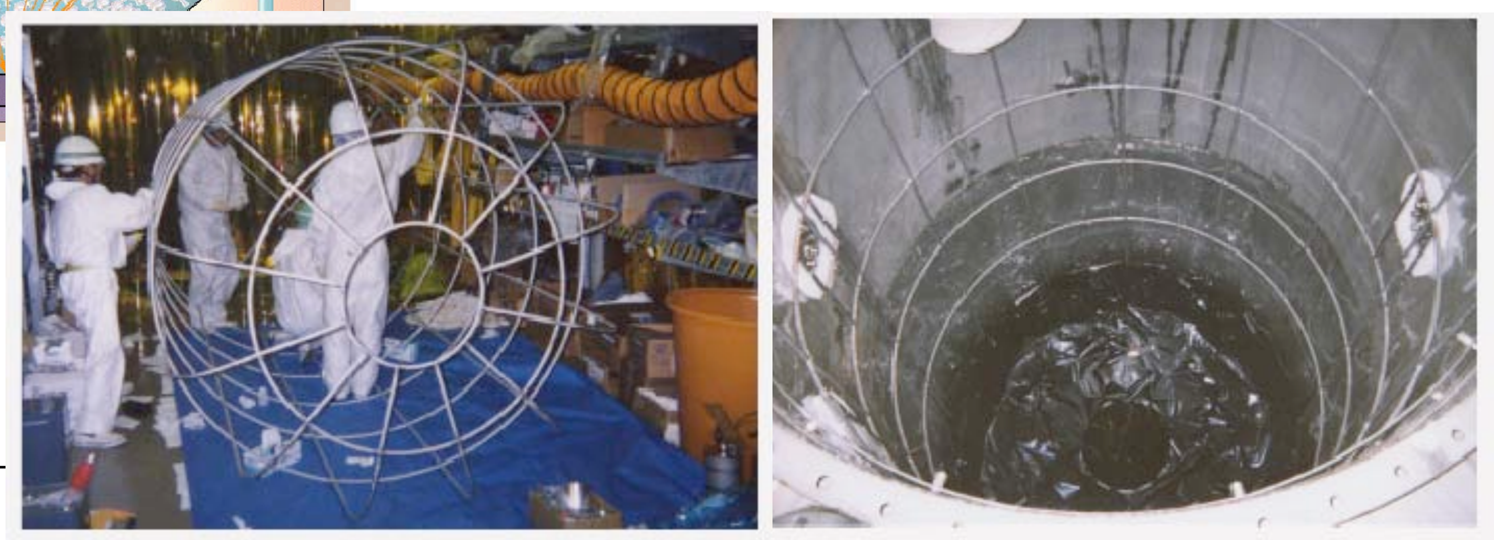
Moving a Pole Segment through the Pin Block



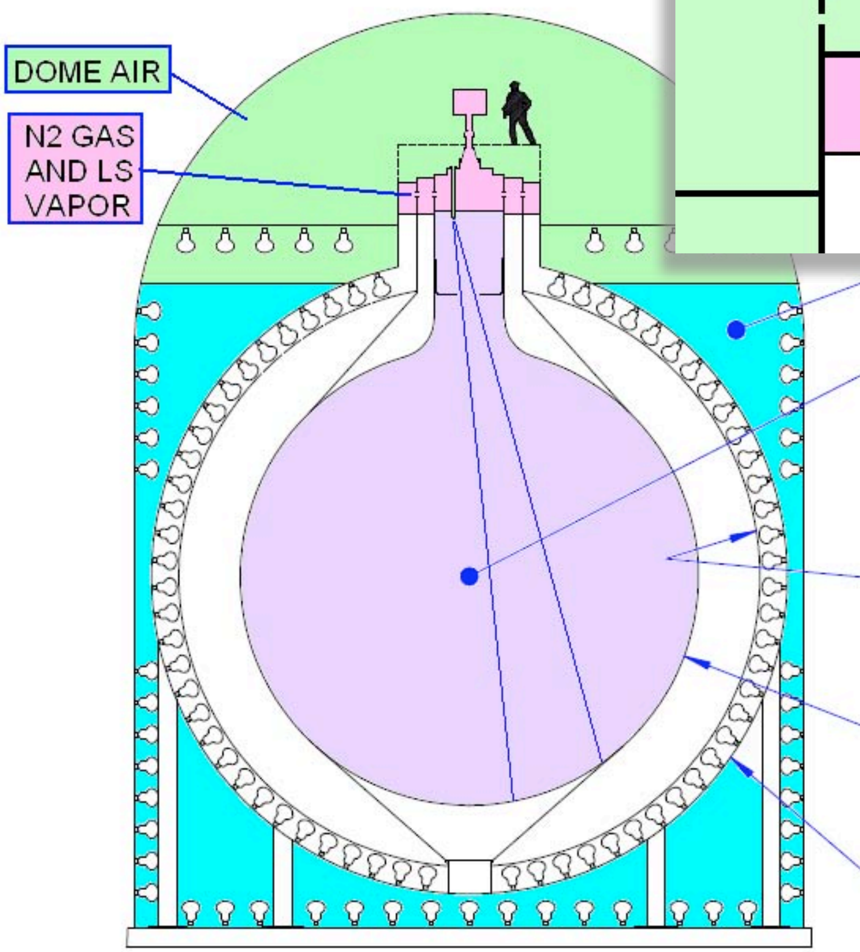
Chimney Structure

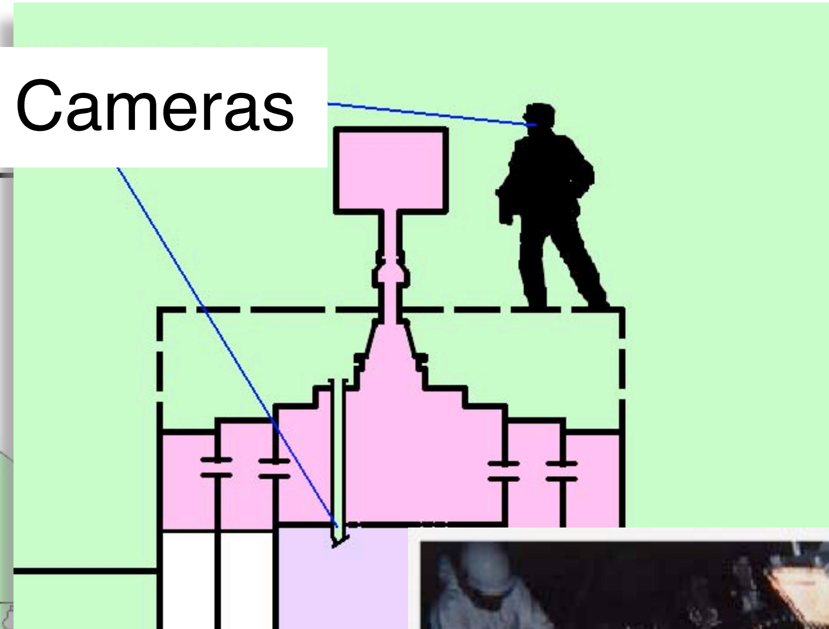


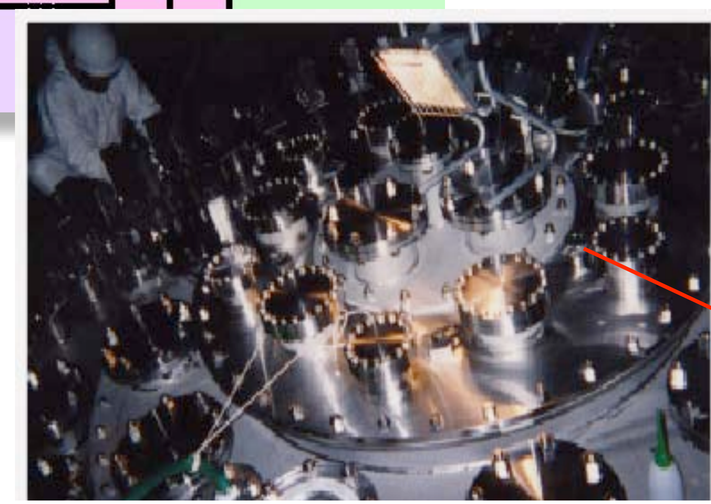




Chimney Monitoring Cameras



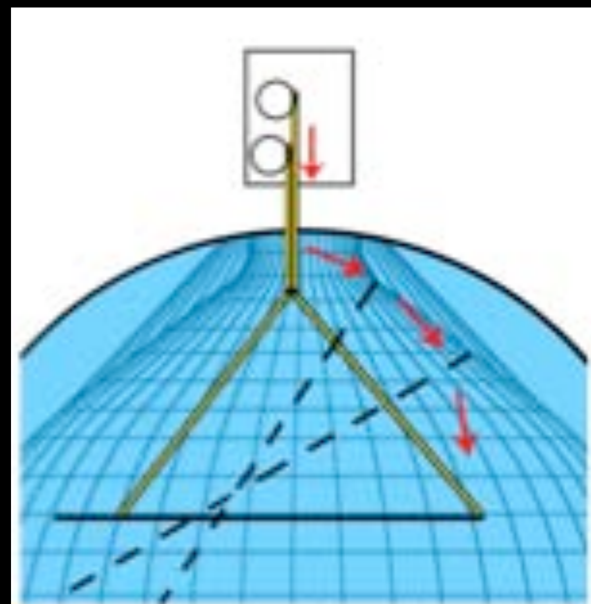




Purpose:

To visually monitor the deployment and retraction of the4pi calibration system.

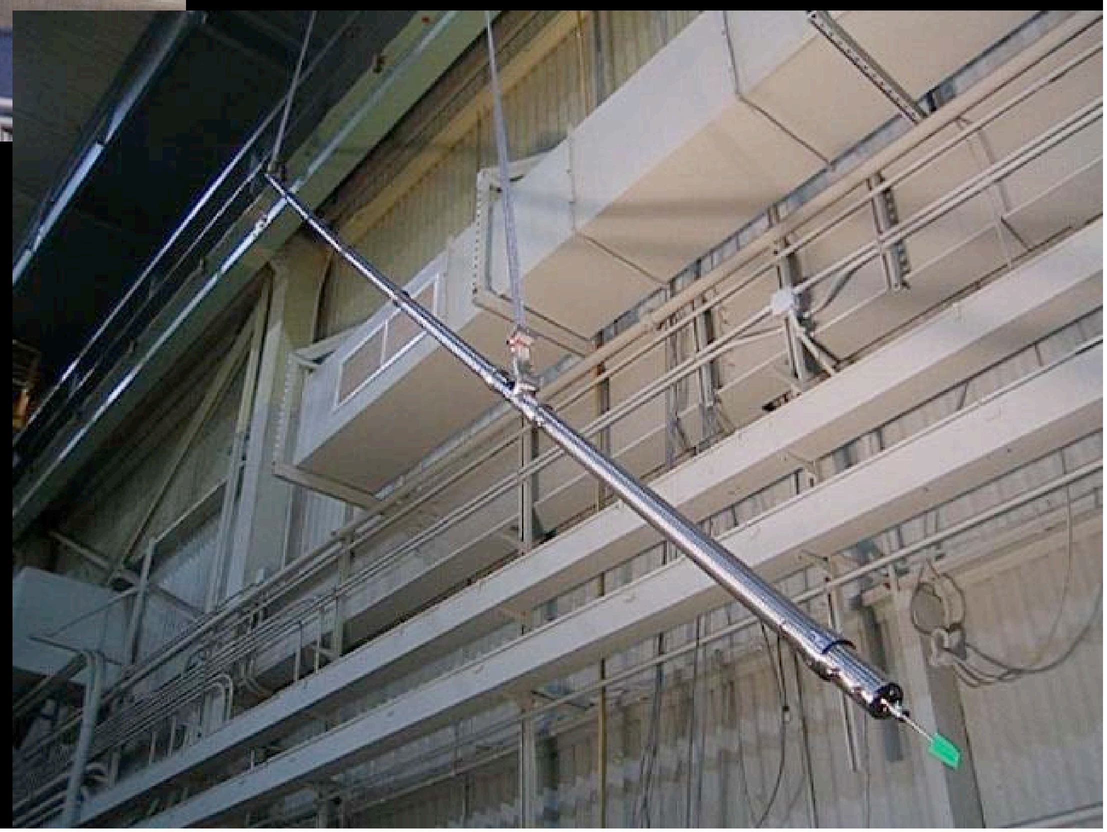
→ optional, conceptual design in place



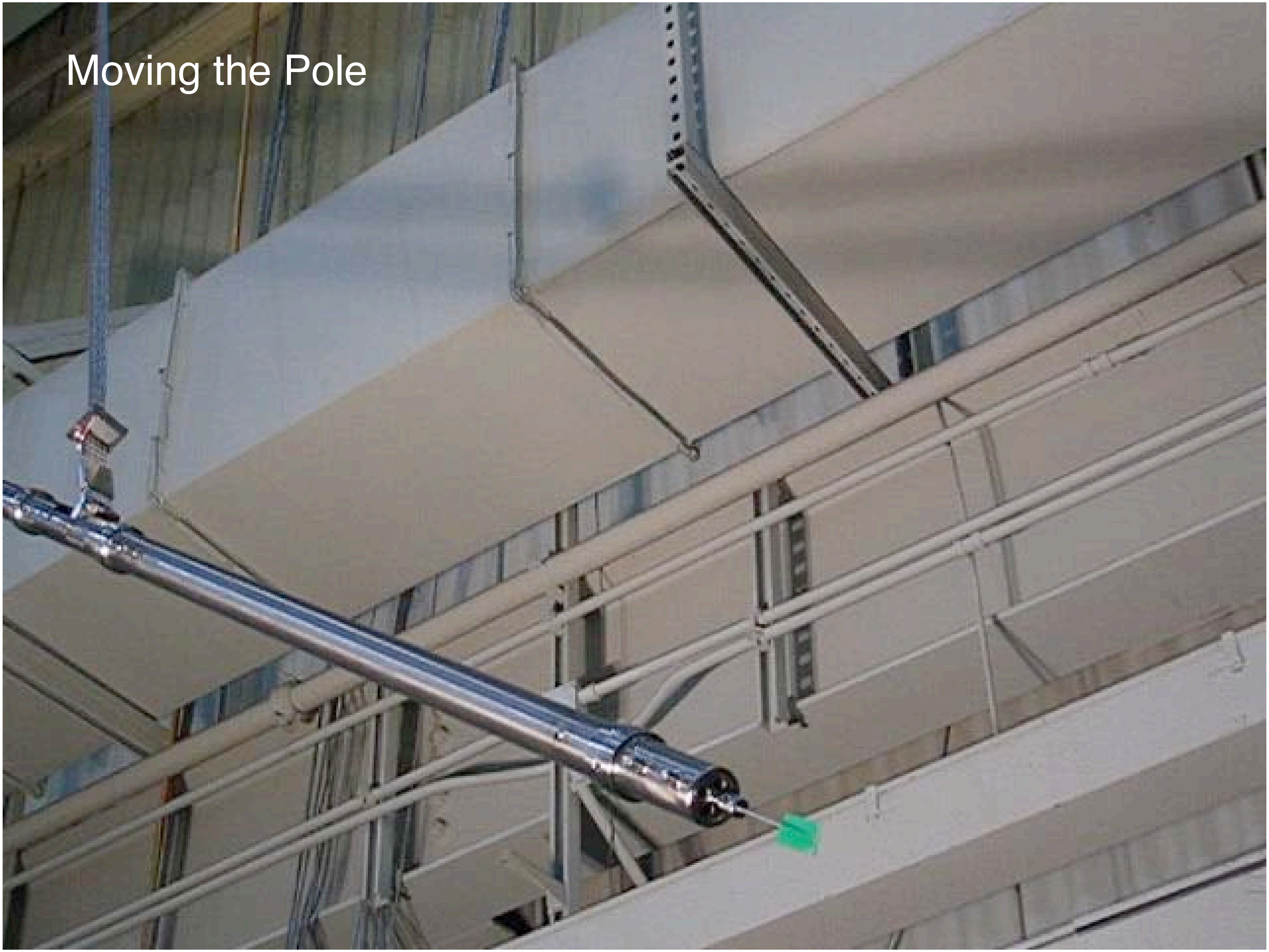
Moving into Position


Moving the Pole in Position

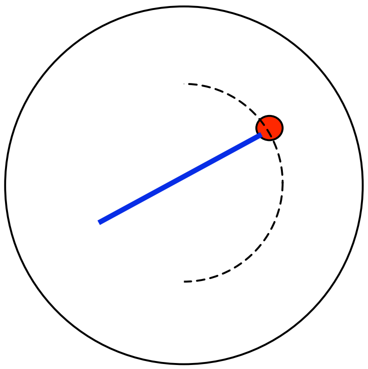
Moving the Pole



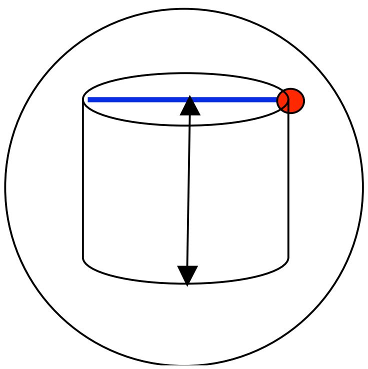
Moving the Pole



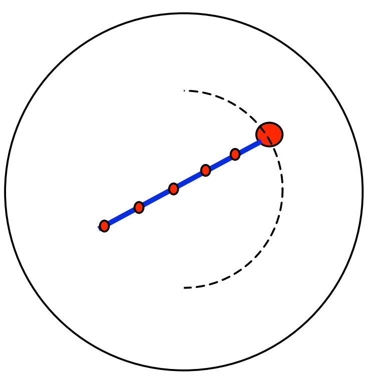
Possible Calibration and Deployment Scenarios



Sweep out semicircles starting from bottom



Cylindrical calibrations with short pole



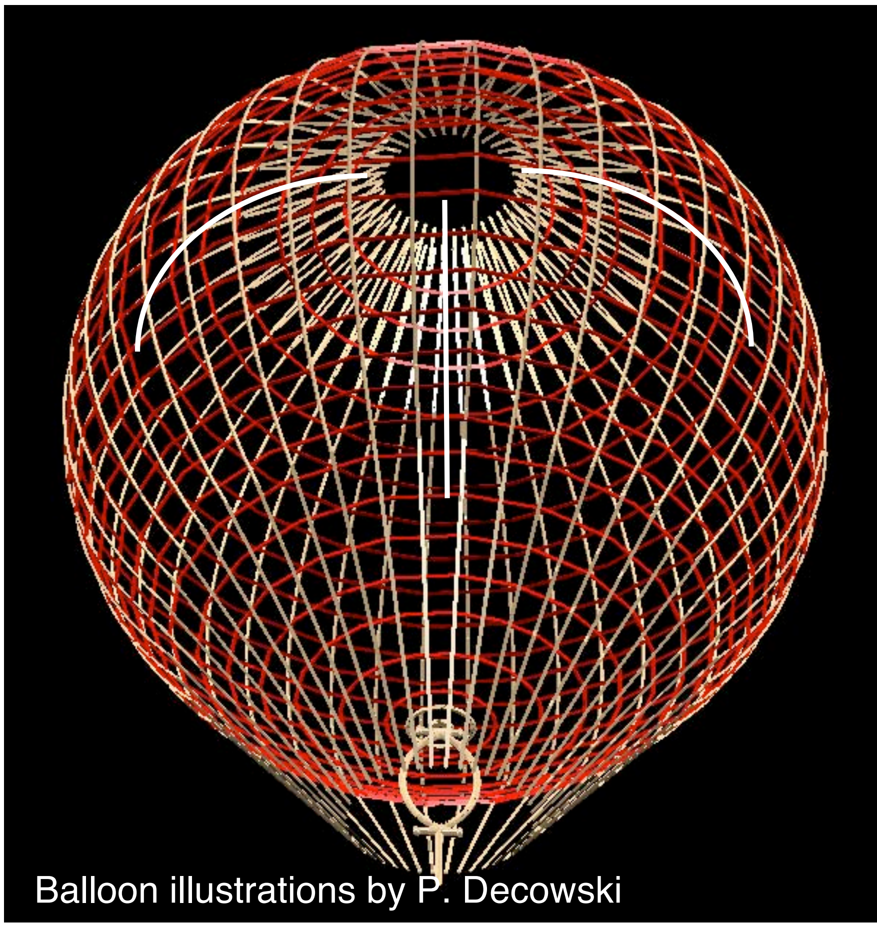
Multiple ^{60}Co source, primarily for vertex reconstruction

Calibrating the Entire Fiducial Volume

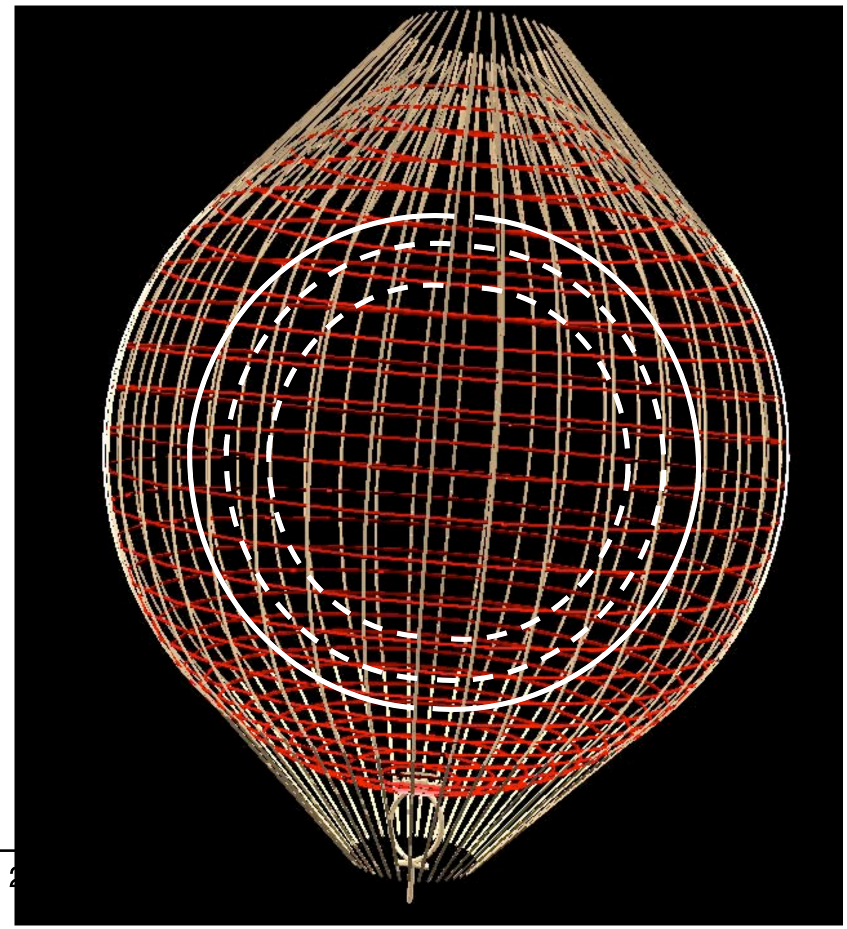
Combination of all of the above deployment scenarios

several ϕ positions
e.g. ϕ=0, 120, 240

various radial positions near fiducial boundary
e.g. R=4.5, 5, 5.5m



Balloon illustrations by P. Decowski



Calibration in Semicircles

Duration:

20min of data taking per point

10min to move pole between points

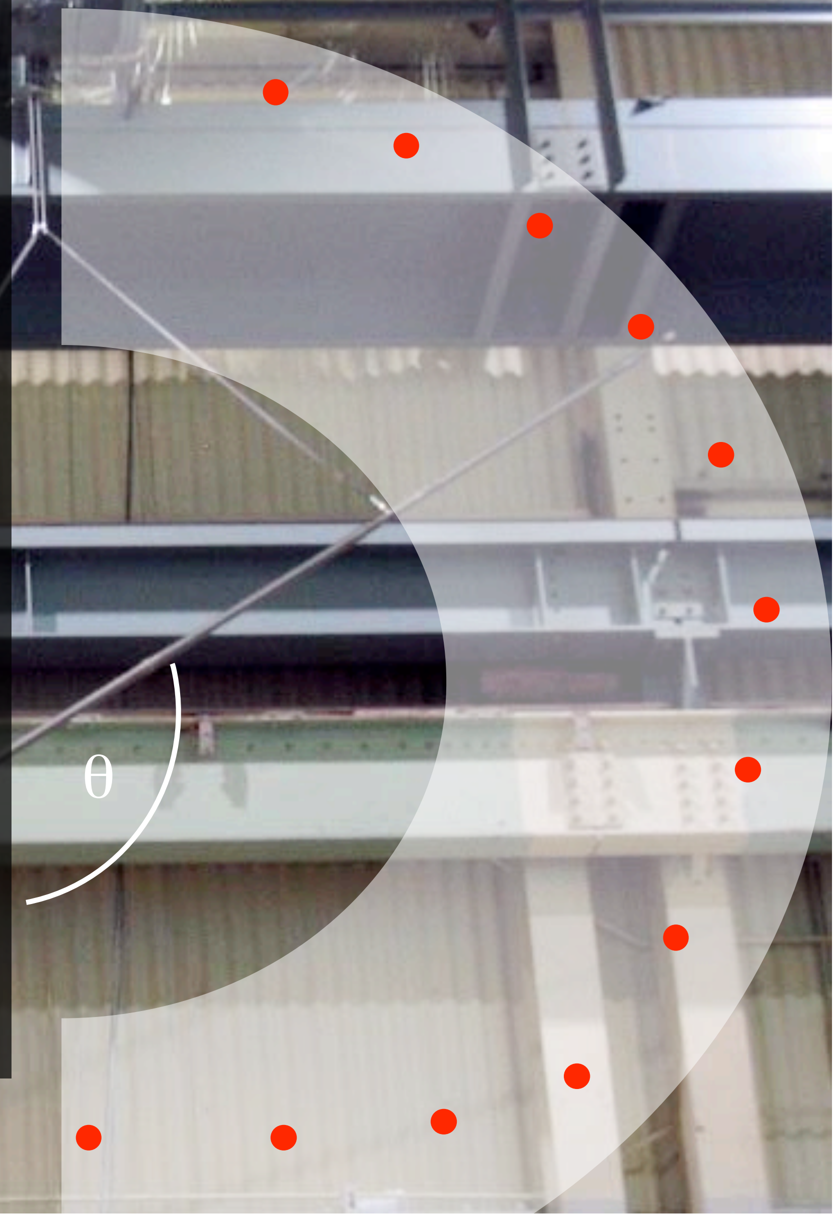
12 points = ~ 6-8hrs of data taking

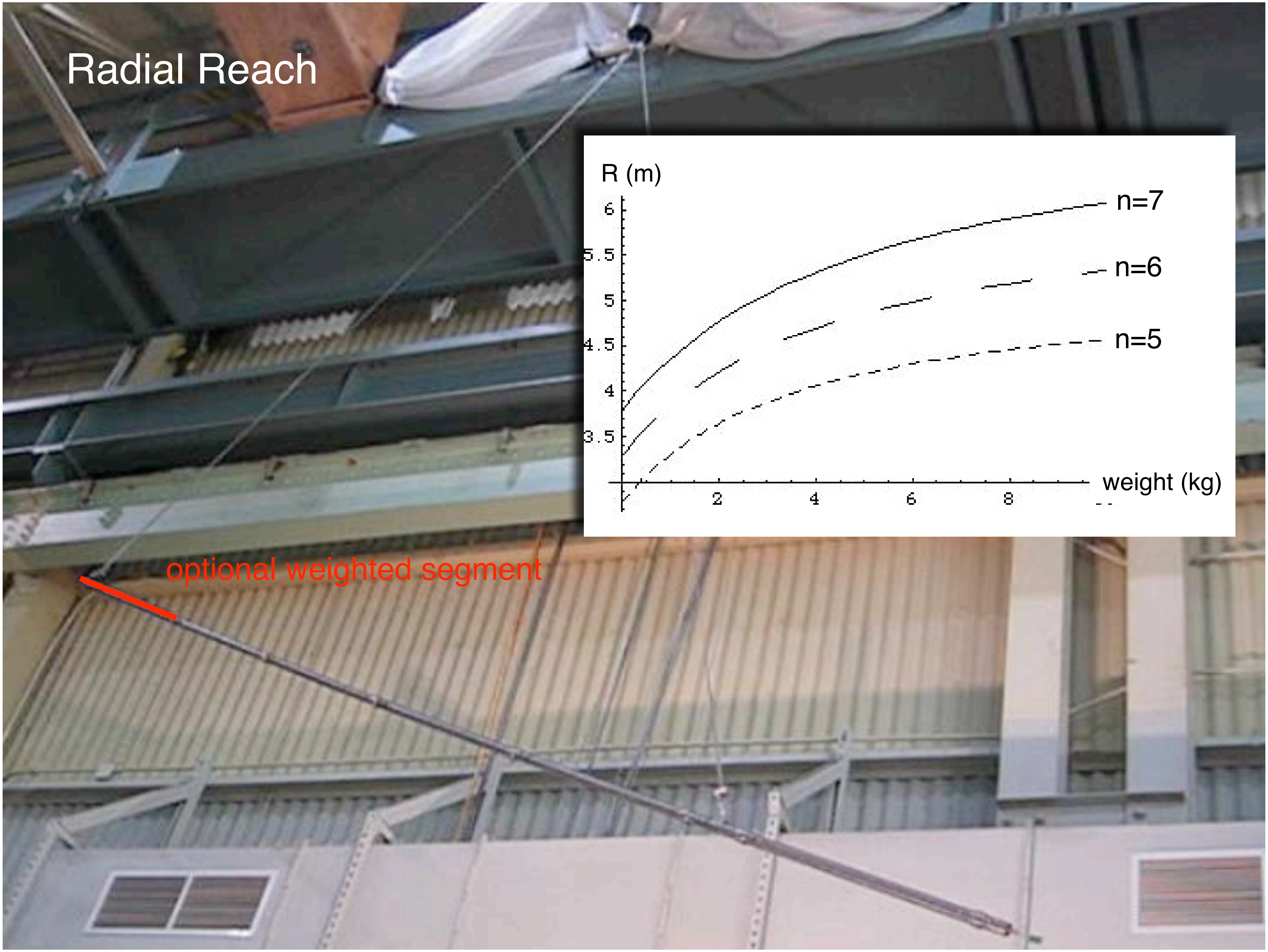
~1 semicircle at 1 radius per shift

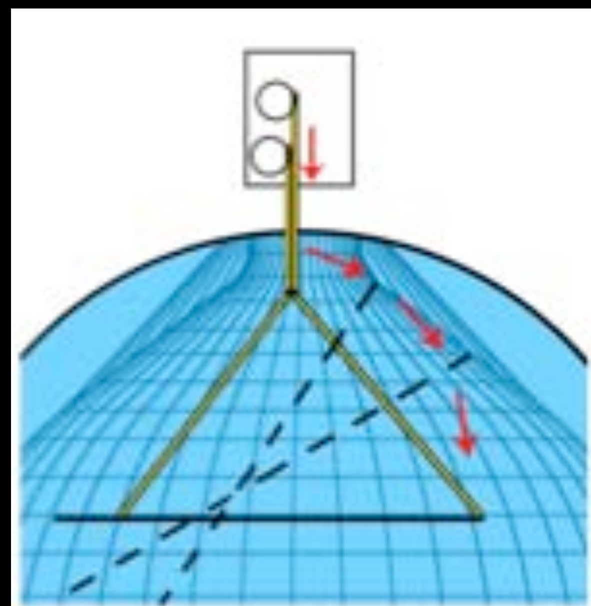
Procedure:

Take half the points on the sweep up and half on the way down to check for possible systematic positioning effects.

Note: Unlikely that we can do more than one radius per shift.



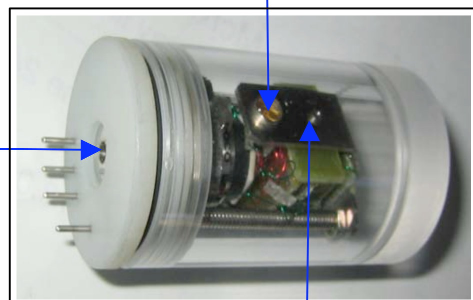

Radial Reach
R (m)
6
5.5
5
4.5
4
3.5
n=7
n=6
n=5
weight (kg)
2
4
6
8
optional weighted segment

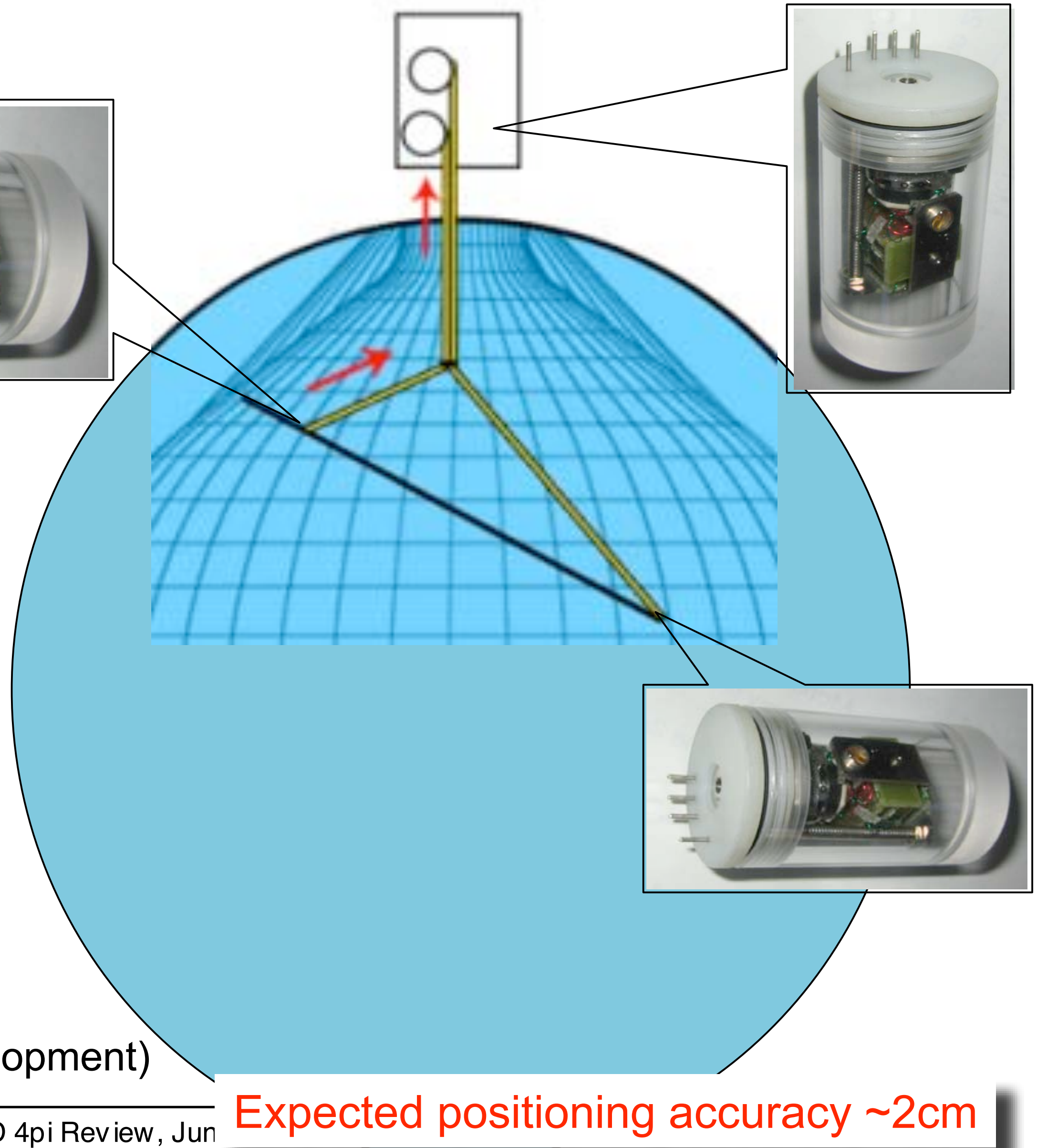


Position Information

Real-time Monitoring and Off-line Reconstruction

Instrumentation of the Calibration System





Position Information:

cable length < 0.5 cm

depth (3 pressure sensors) < ~2 cm

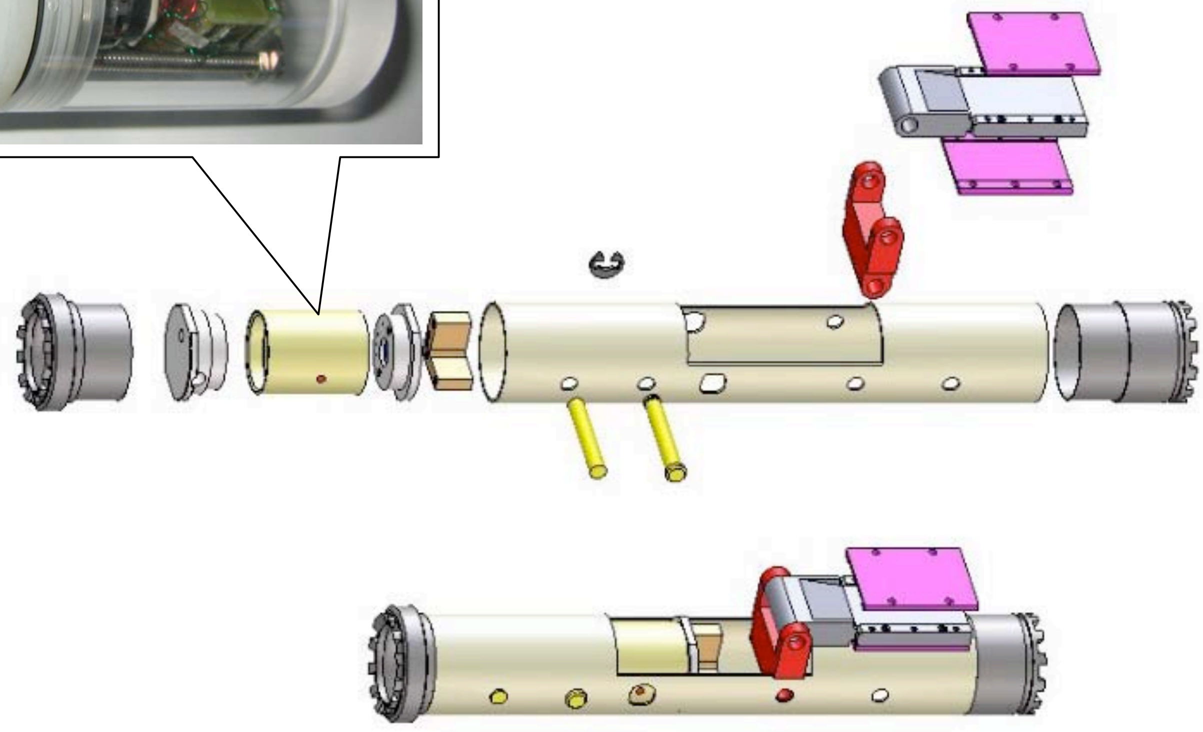
inclination of pole (accelerometers)

Co-60 sources

CCD imaging of IR LEDs (under development)

Expected positioning accuracy ~2cm

Cable Attachment and Instrumentation Holder

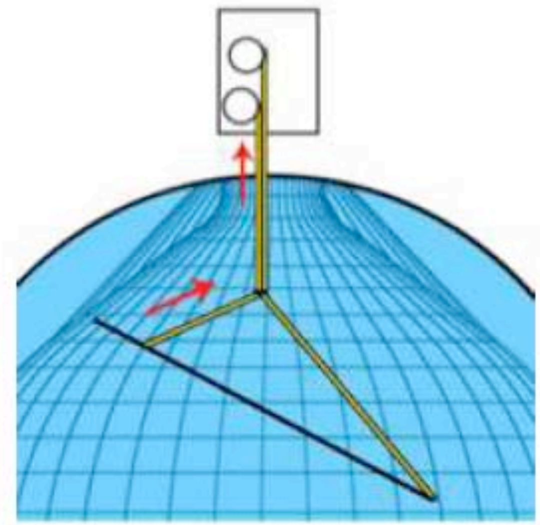


The Goal is to know the Position of the Source to 2cm.

Active or On line Instrumentation:
- Pressure Sensor.
- Tip Tilt Sensors.
- LEDs for use with CCD cameras.

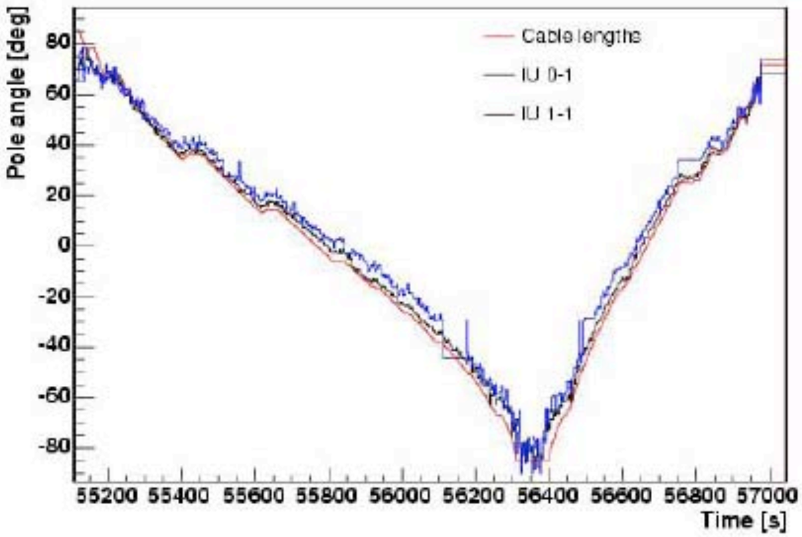
Passive or Off line Instrumentation:
- Reconstruction of Co60 sources in poles.
- Reconstruction of LEDs

Additional Analysis Underway:
- Understanding of Shadowing using MC.
- Measurements of pole deflections.

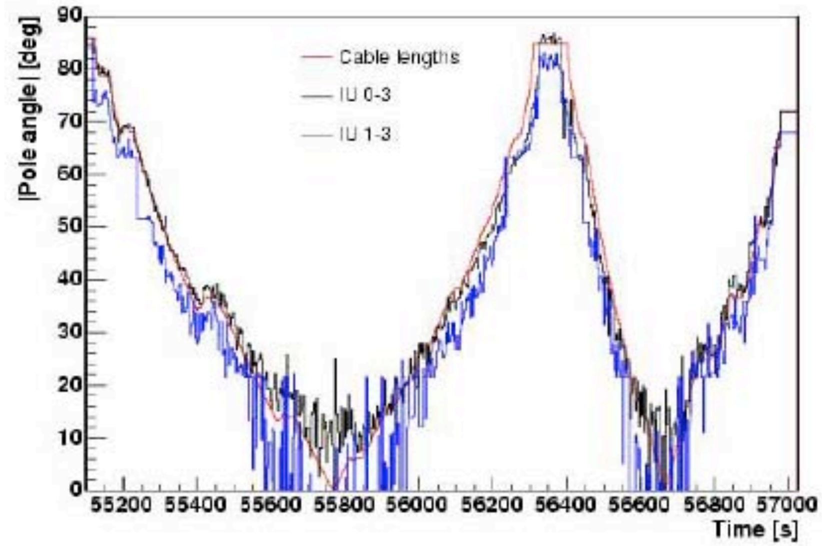


Testing the Inclinometers on Two Units:

Pole Angle From Axis One:

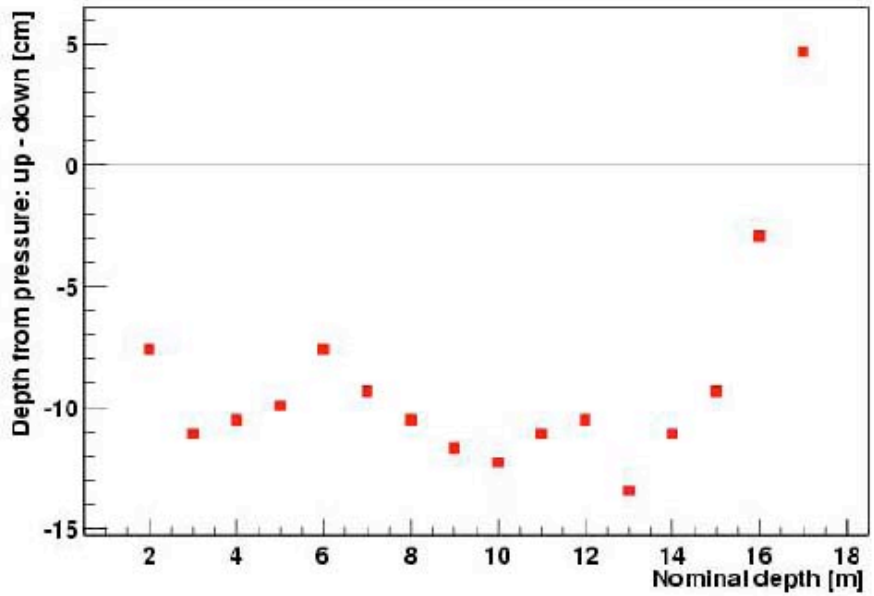


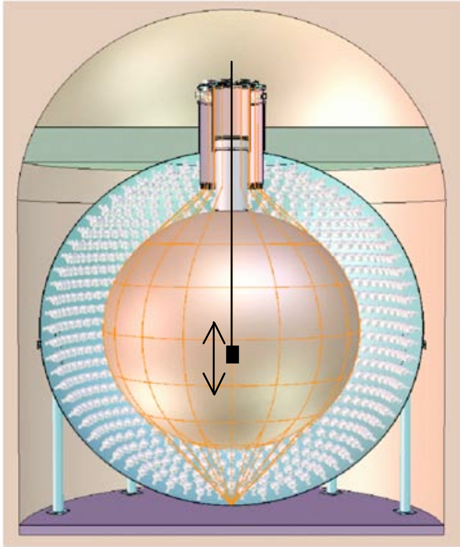
Pole Angle From Axis Two:



The inclinometers agree well with the angle calculated from the cable lengths as you take the pole from horizontal to vertical and back, but to get more accurate measurements you will need to survey level and calculate a rotation matrix for each unit when installed in the pole.

Testing the pressure sensor in KamLAND



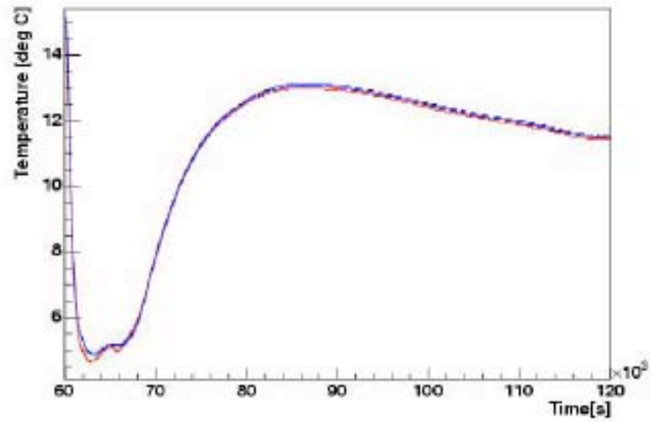


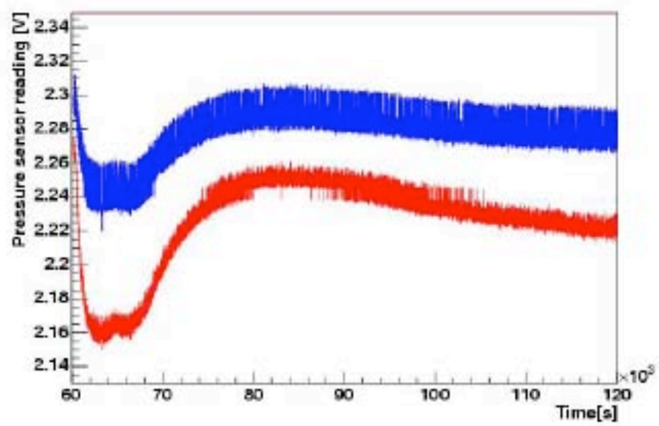
A test deployment along KamLAND's z-axis showed a 10cm position deviation between data going down and data going up. It was also noticed that the pressure sensor registered a change in pressure when the operator put his hands in the glove box.

-> Will install reference pressure sensor in glovebox

Pressure Deviation Due to a Temperature Effect

Two units were placed in a beaker of water as ice was added and the temperature and pressure was monitored as they cooled down.

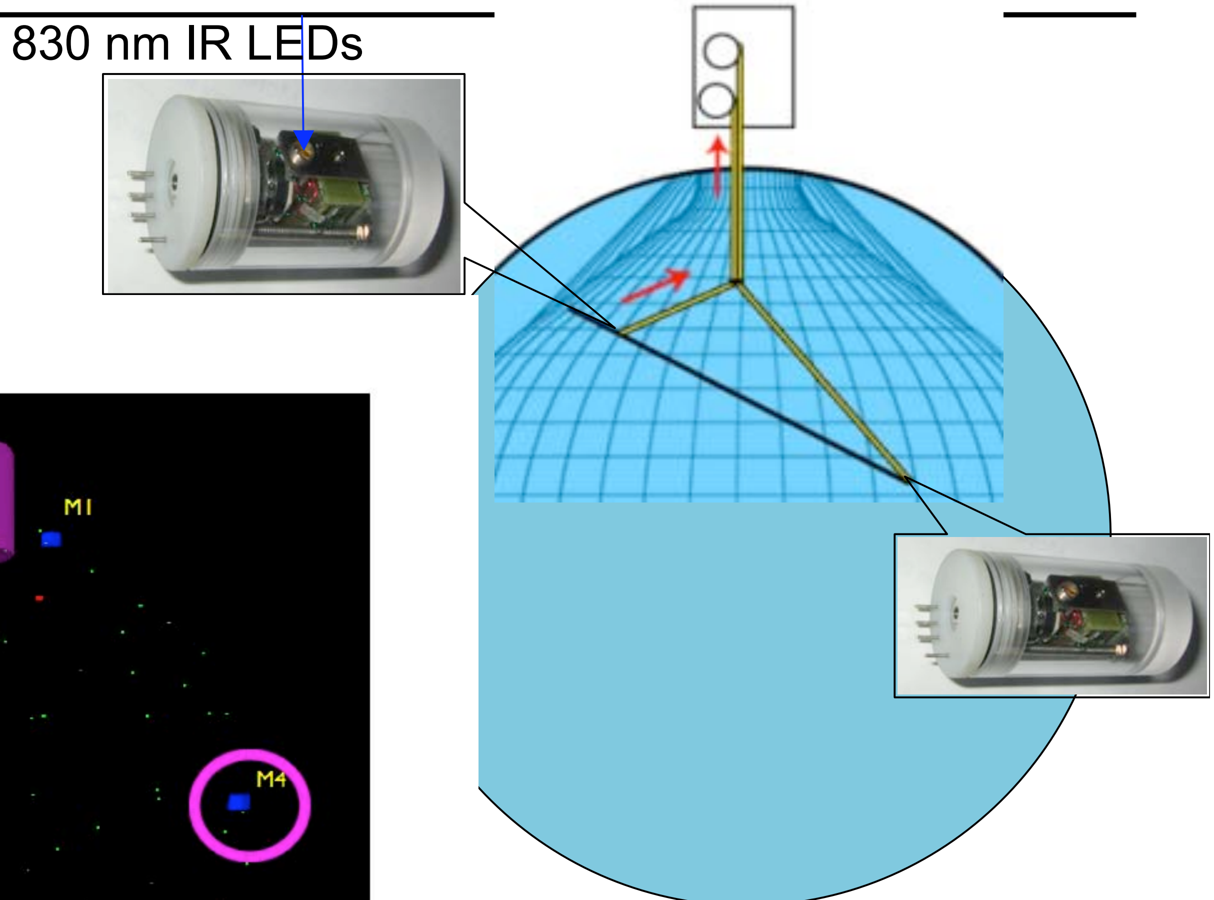




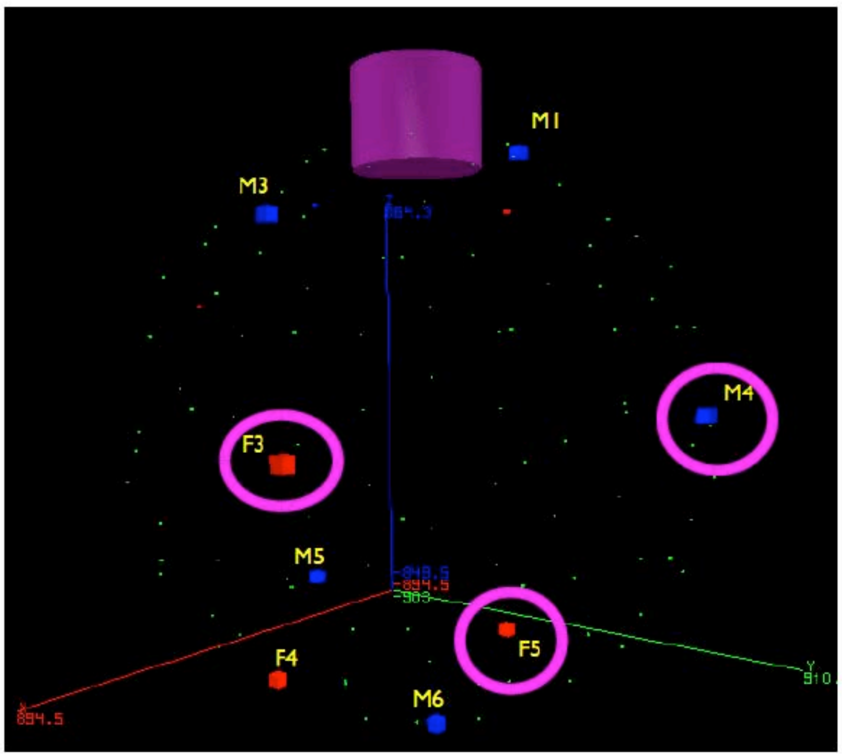
Improving Pressure Accuracy:

- Put Instrumentation Unit in glove box to provide a reference pressure and temperature.
- Pressure vs. Temperature curves for all units to calibrate out temperature effects.
- Construct holder for all three units and deploy together on the new z-axis system to calibrate their relative response. *

LED Imaging Under Development

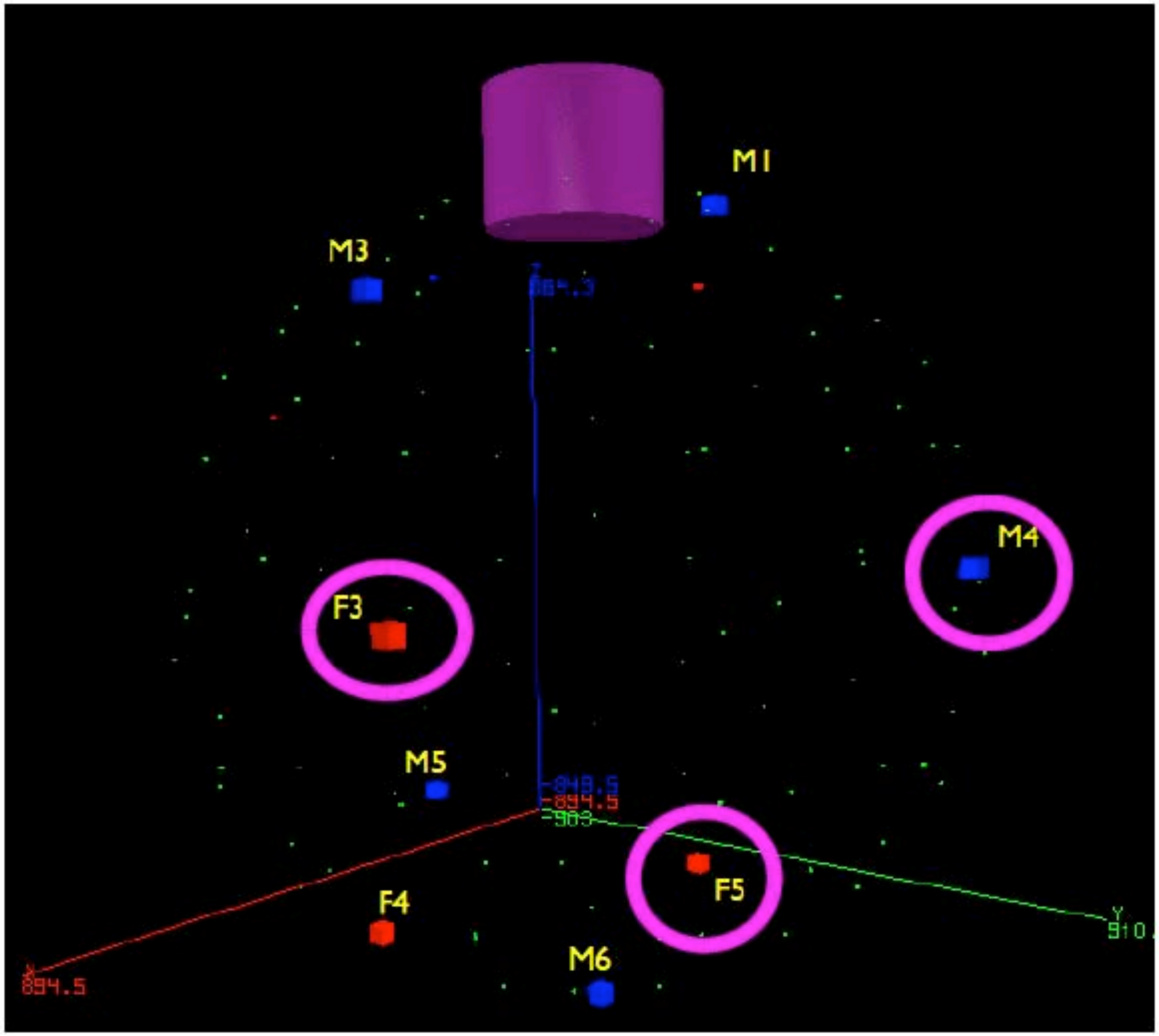


Test of CCD Camera's and LEDs:



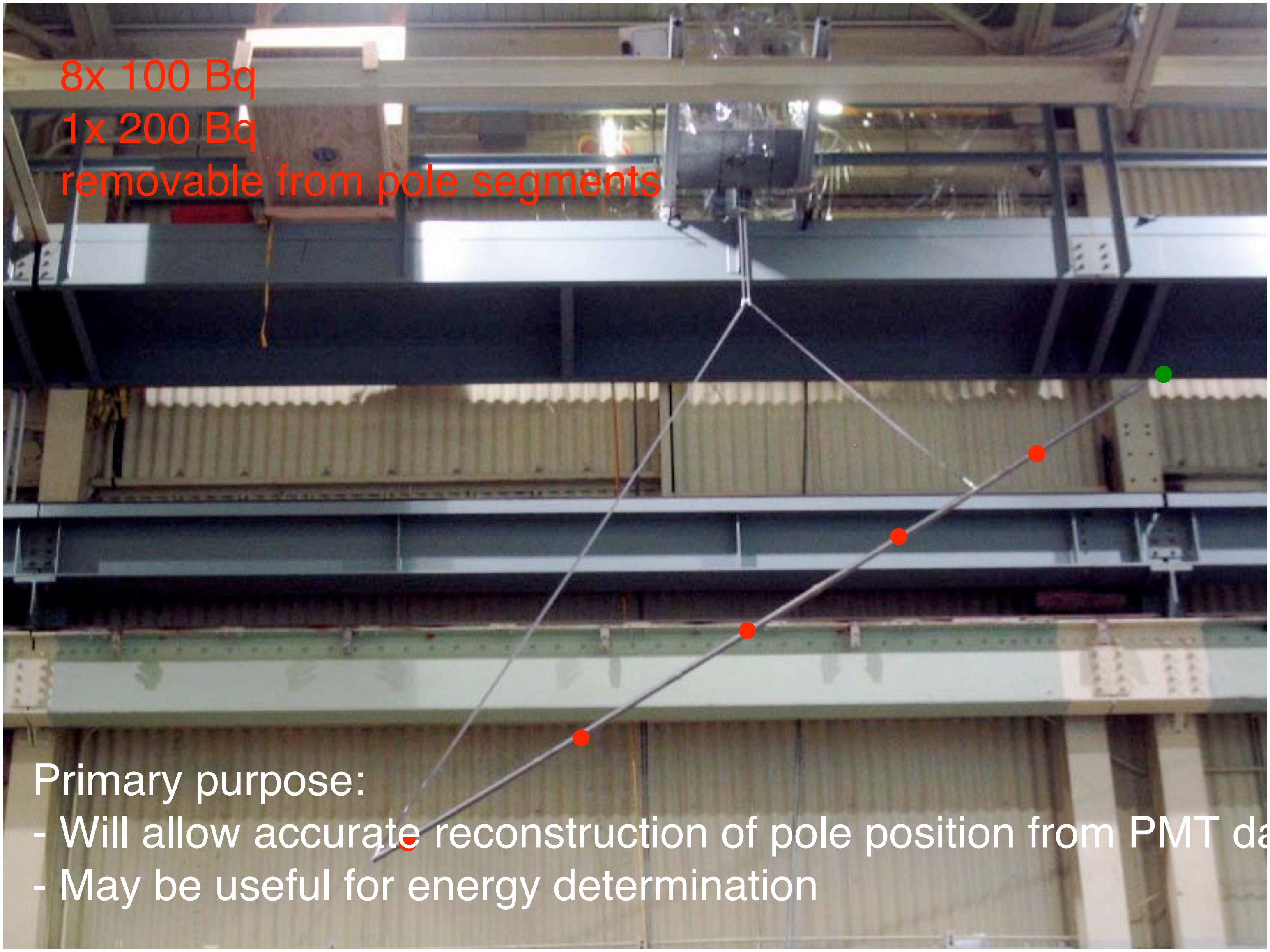
Circled cameras saw the LEDs when the unit was at the bottom of the detector.

Test of CCD Camera's and LEDs:

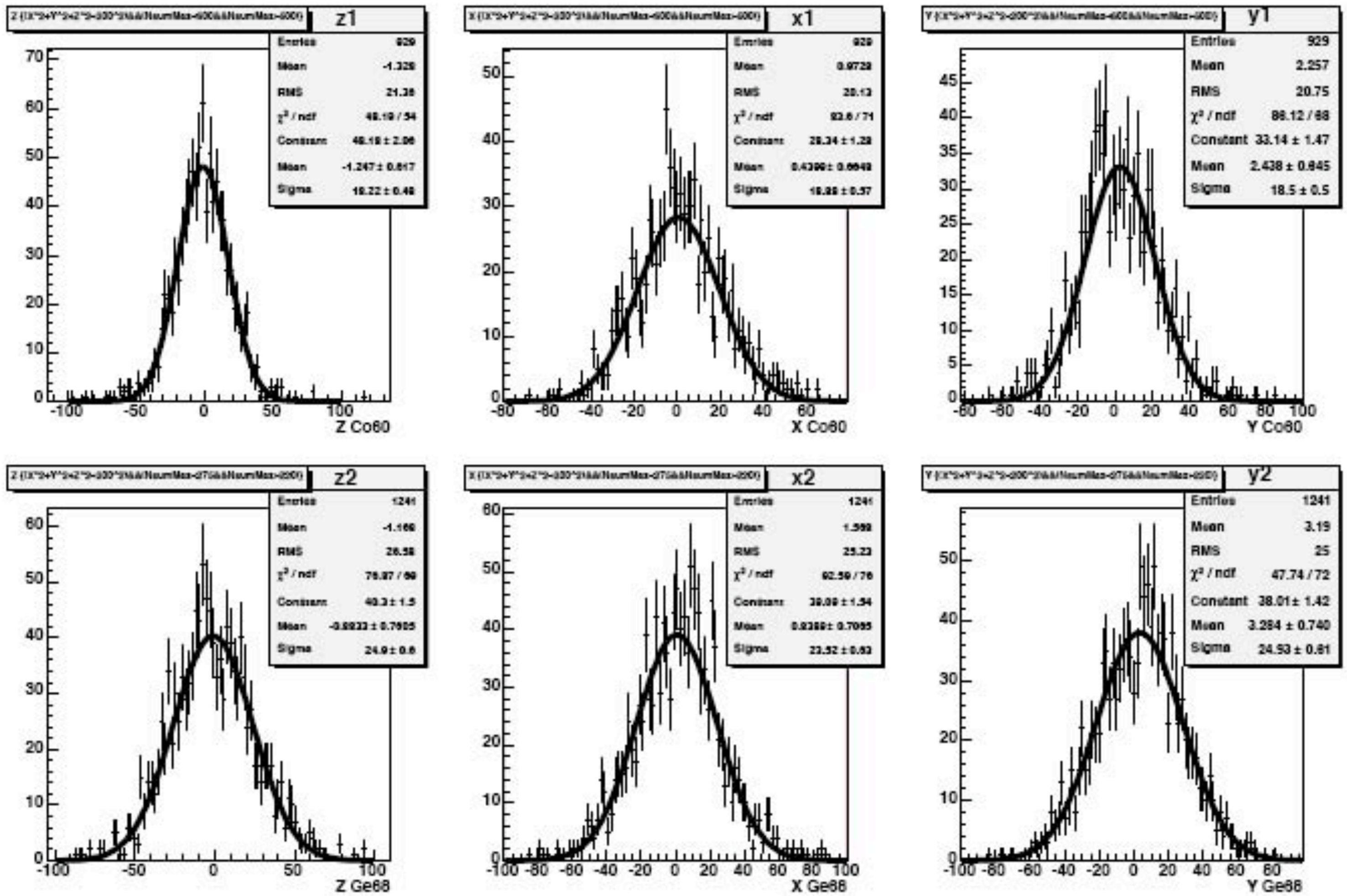


Circled cameras saw the LEDs when the unit was at the bottom of the detector.

Removable ^{60}Co Sources in Every Pole Segment

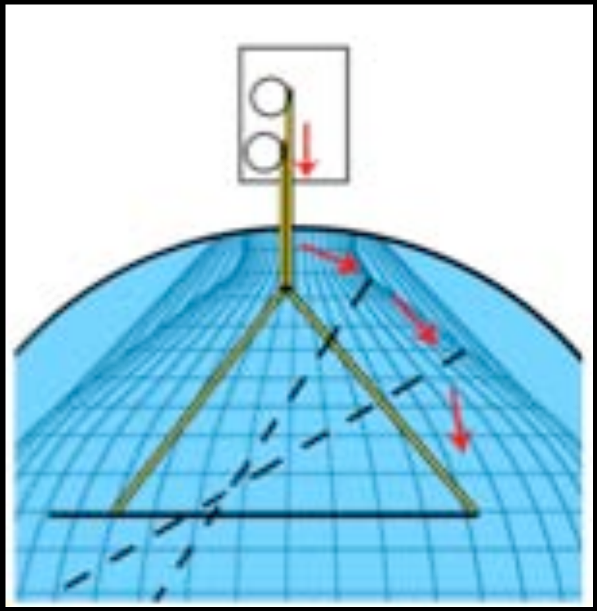


Offline Reconstruction of 60Co Sources



T. Classen

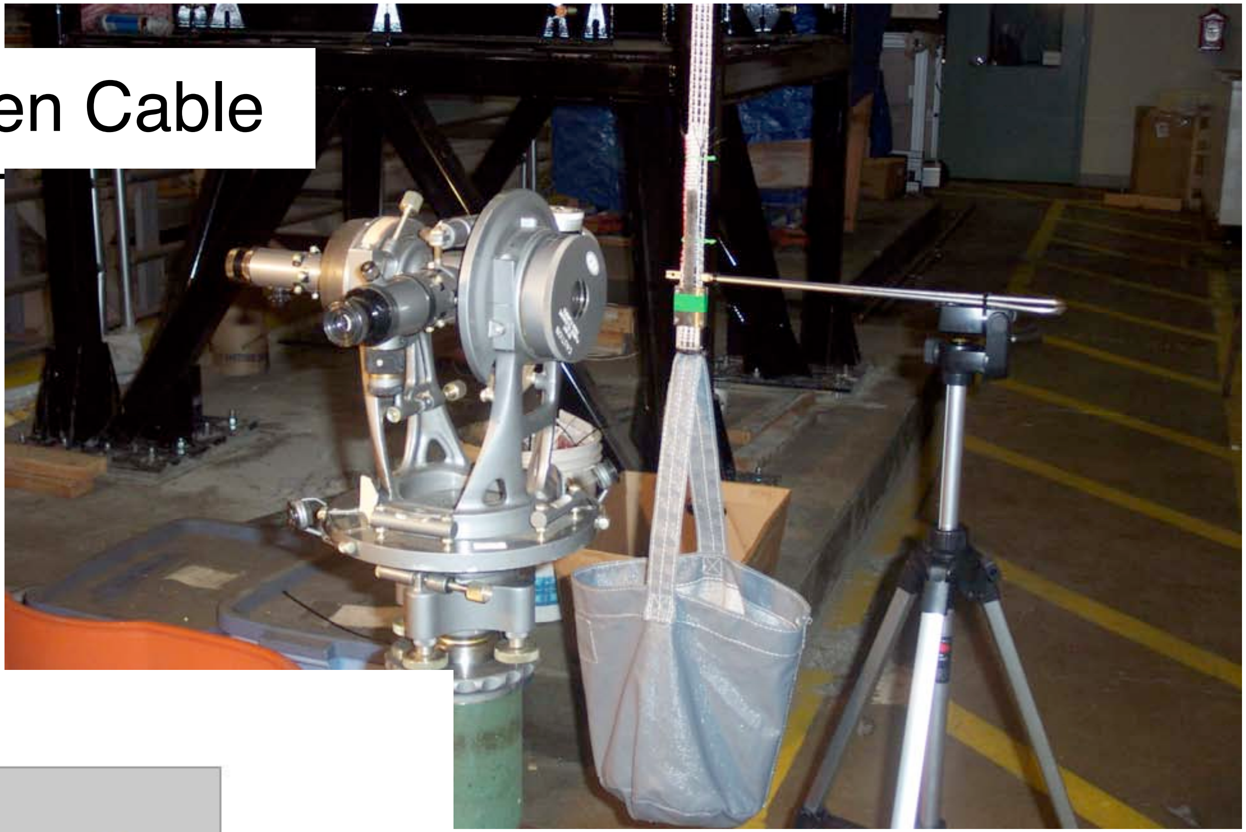
Figure 1: run 4398 position reconstruction, approximately 1000 Co-60 events



Positioning Performance

- How accurately can we position the system?
- How accurately do the calculations of the control software and the measured position agree?

Stretch of the Woven Cable



The cable stretched ~6.8 mm with a total of ~10.4 kg of weight on it.

The cable does show a small amount of hysteresis between removing and adding weight.

Survey procedure

- Use Kern digital readout theodolite on loan from ALS alignment group.
- Stabilize pole in ϕ with guide wires.
- In vertical position, calibrate distance from pivot block to cable attachment points and source.
- Make pole level in horizontal position, and tune pole CG parameter so that control program agrees.
- In vertical, horizontal, $\pm 30^\circ$, and $\pm 60^\circ$ positions, sight pivot block, cable attachments, source, and small ^{60}Co pin locations.
- To this point, only done with a 4+1 segment pole; we will repeat with all pole configurations that we plan to use.

Agreement between control program and survey

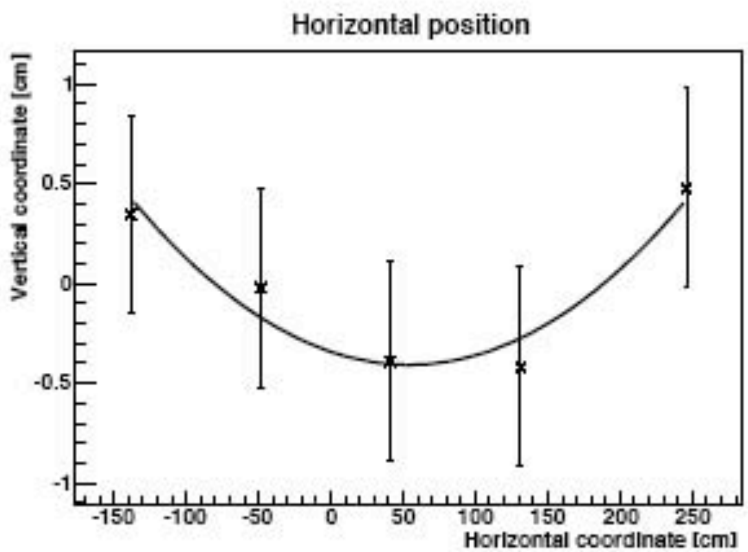
Configuration	Cable 1 end (dx, dz)	$\sqrt{dx^2 + dz^2}$	Source end (dx, dz)	$\sqrt{dx^2 + dz^2}$
H	(0.95 -0.05)	0.95	(1.57 -0.01)	1.57
V	(-1.33 2.72)	3.03	(-0.97 0.90)	1.32
-30°	(-0.91 1.35)	1.63	(-1.33 2.05)	2.44
-60°	(-2.01 2.80)	3.45	(-2.80 1.82)	3.34
+30°	(0.14 2.56)	2.56	(-1.51 1.49)	2.12
+60°	(4.58 -0.98)	4.68	(-3.61 4.28)	5.60

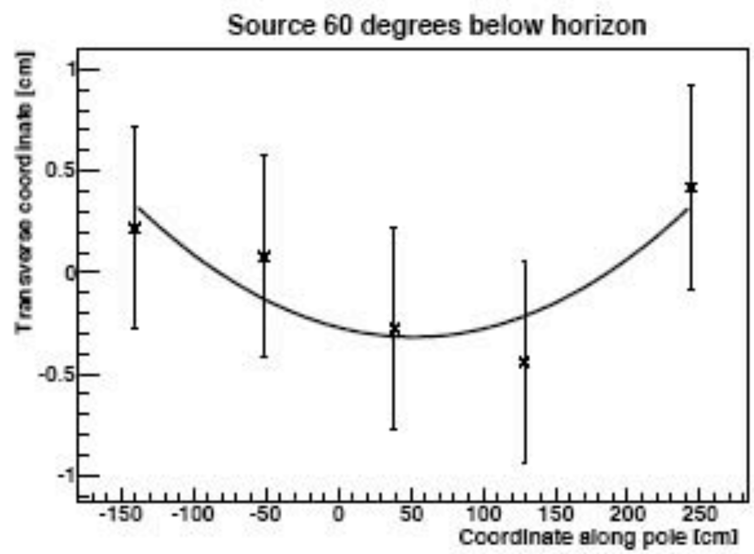
[All dimensions cm]

- within ~3.5 cm (worst case seen that is not otherwise explained).
- in +60° configuration, cable clamps do not hang parallel to cable.

Pole deflection

- Positions of small ^{60}Co source pins were surveyed in each position for 4+1 segment pole:

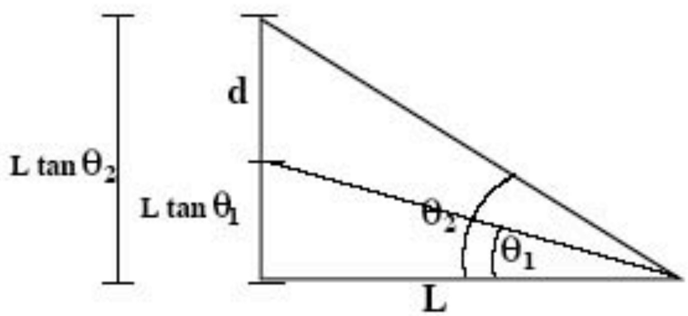


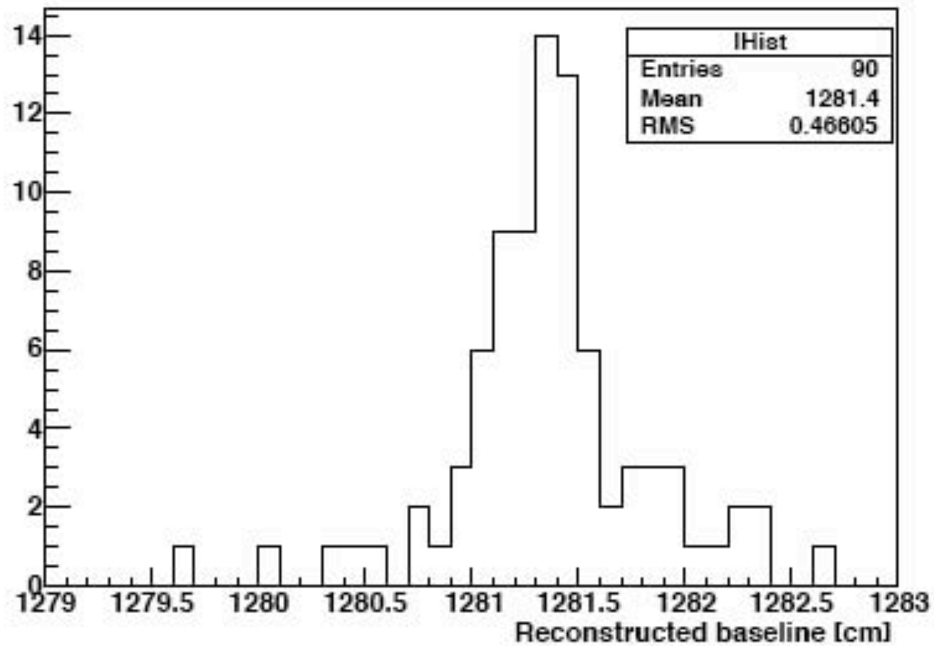


- Maximal deflection of $\sim$1 cm in this configuration

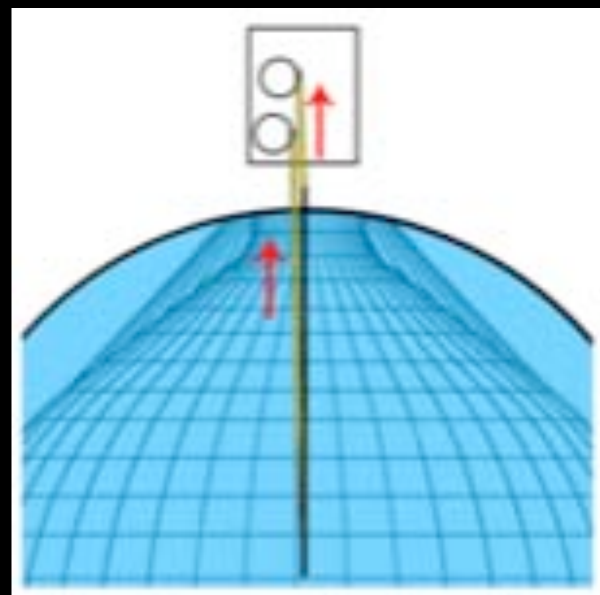
Calibration of transit baseline

- Tape measure suspended from flange center.
- 15 points sighted along tape; 90 distinct pairs at least 1 m apart.





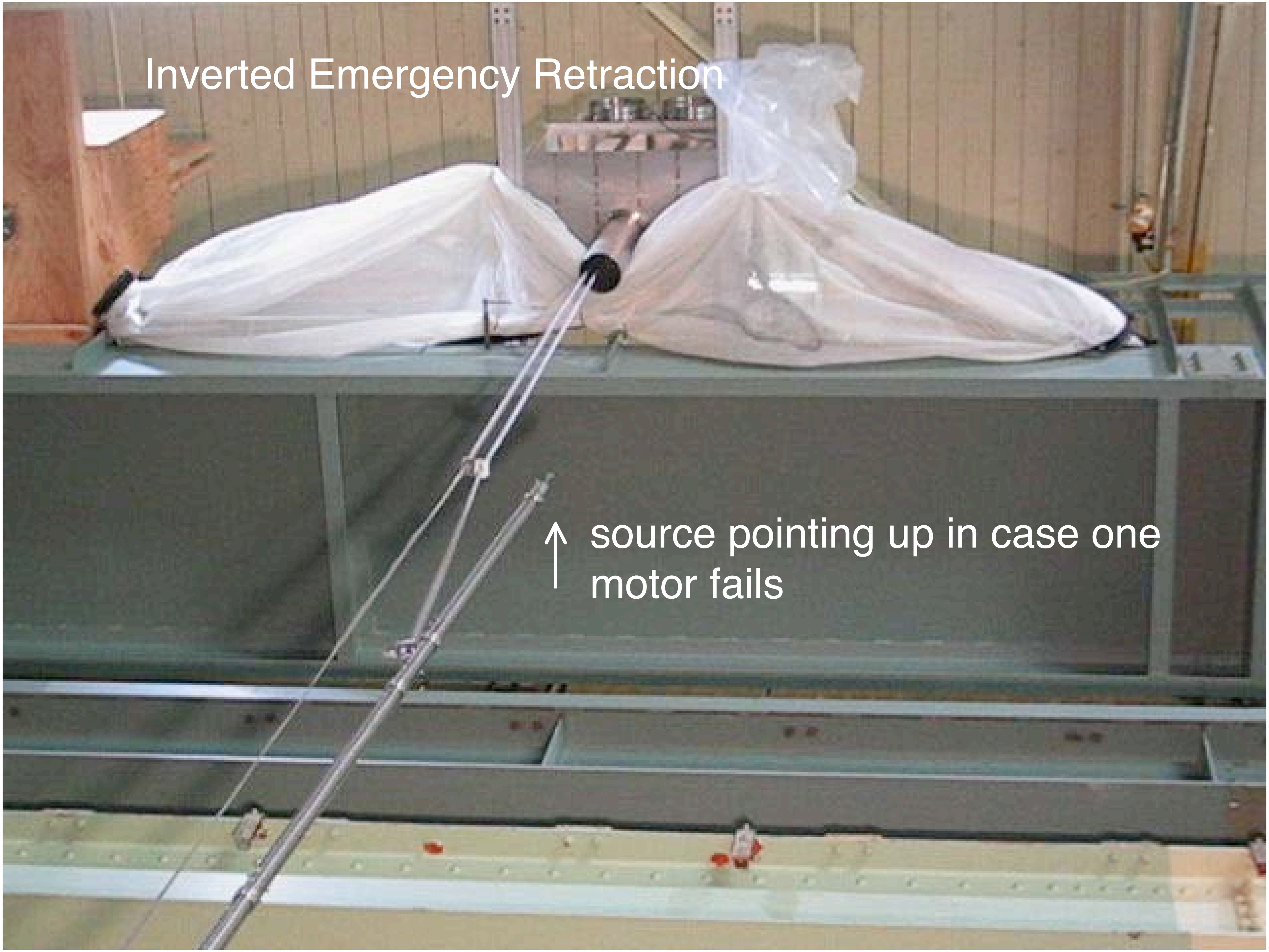
- Surveying accuracy is $\sim$0.5 cm (1 σ) for each point.



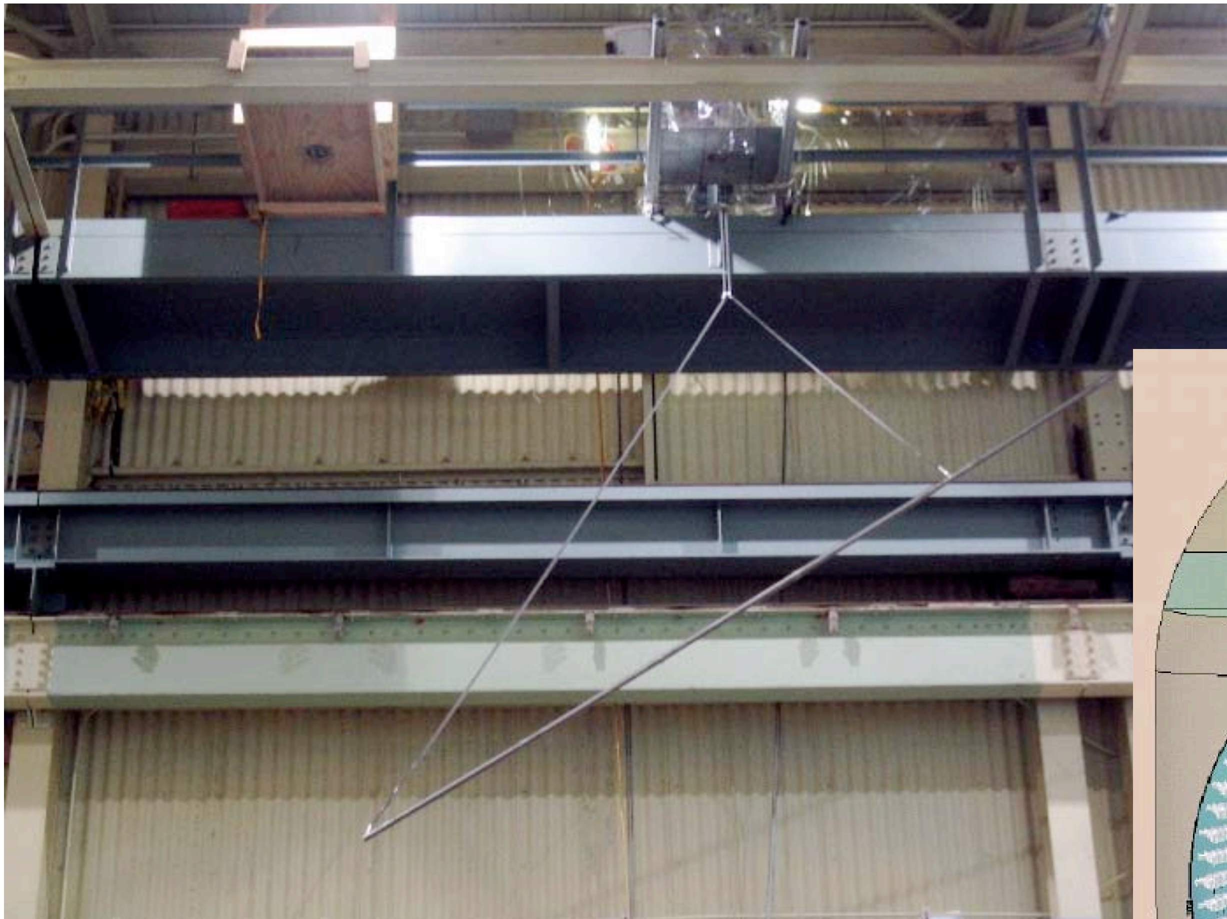
Retraction

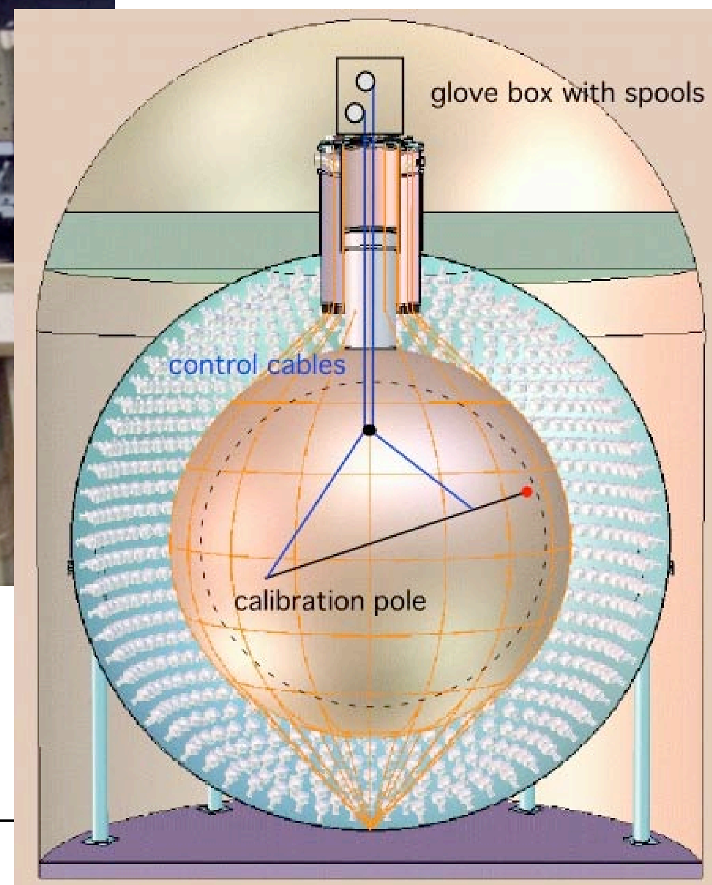
We need to be able to remove the system under all circumstances!


Normal Retraction
source pointing downwards for safety


Inverted Emergency Retraction
source pointing up in case one motor fails

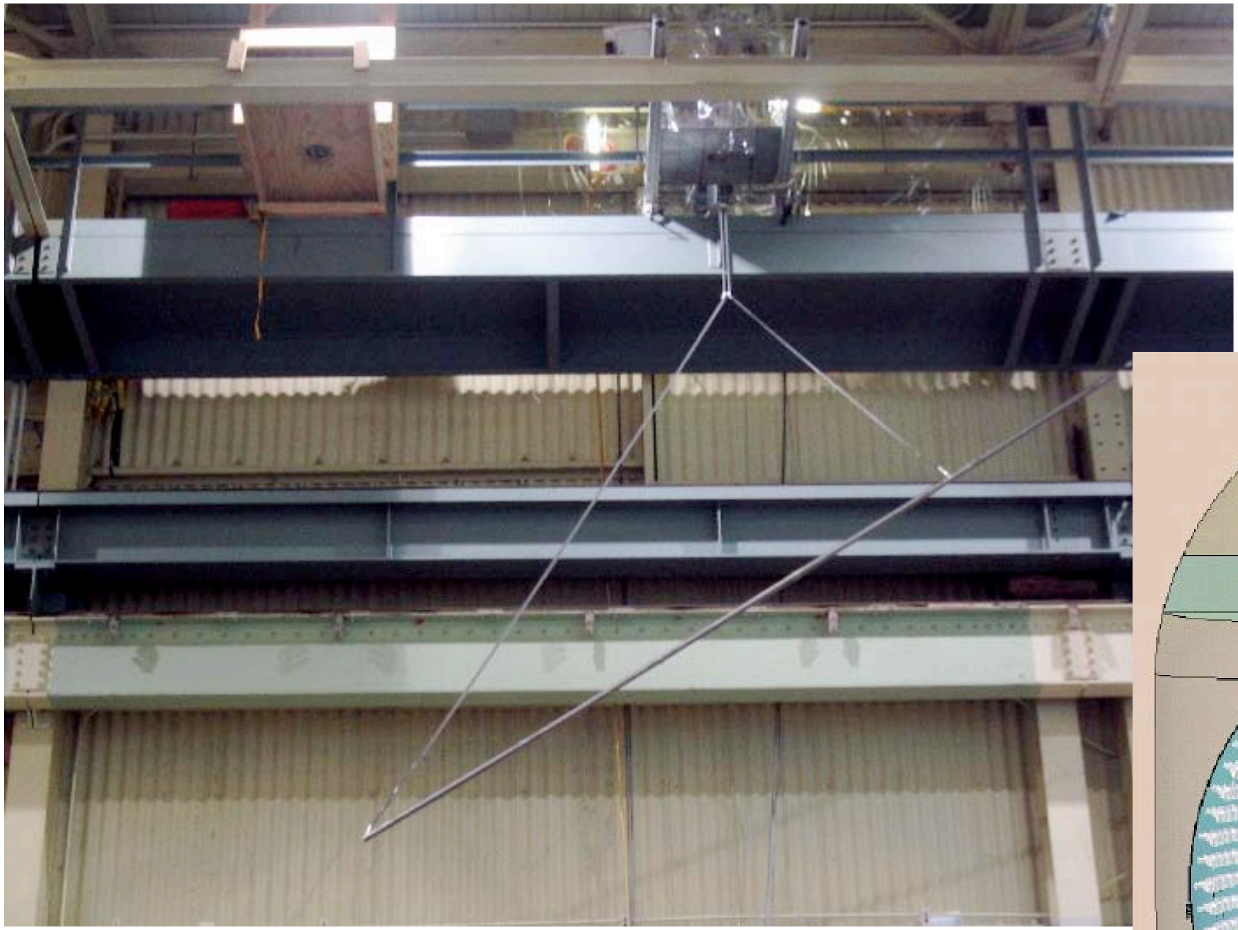
Emergency Recovery Options for the 4pi System

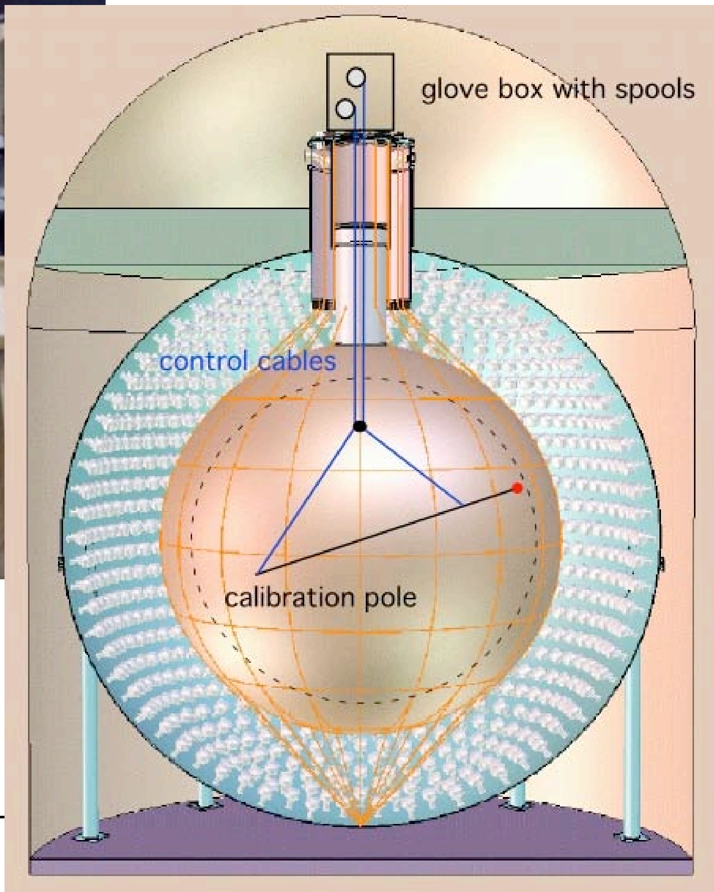




How can we retract the system from any state in the detector?

Emergency Recovery Options for the 4pi System





Recovery may require raising or lowering of cables!

Failure Modes and Actions

1. Control Failures

Power Outage

$\Rightarrow$ UPS $\Rightarrow$ Computer and software recovery

Computer Crash

$\Rightarrow$ restart computer $\Rightarrow$ restart controls $\Rightarrow$ read last position from database $\Rightarrow$ move system back into neutral position $\Rightarrow$ tare system

Software Crash

$\Rightarrow$ restart controls $\Rightarrow$ read last position from database $\Rightarrow$ move system back into neutral position $\Rightarrow$ tare system

-> Fred demonstrated robustness of system yesterday.

Failure Modes and Actions

2. Hardware Failures

Instrumentation Unit

⇒ move system back into neutral position using cable length measurements ⇒ retract pole ⇒ excange IU

Motor 2 or GearBox 2 (lower spool)

⇒ secure system and think!

⇒ retract pole using motor 1 (normal retraction)

⇒ lower cable 2 as needed

Motor 1 or GearBox 1 (upper spool)

⇒ secure system and think!

option 1: ⇒ retract pole using motor 2 (inverted retraction)

option 2: ⇒ manipulate both cables manually

What do you need for emergency recovery?

1. Securing the system with cable clamp √

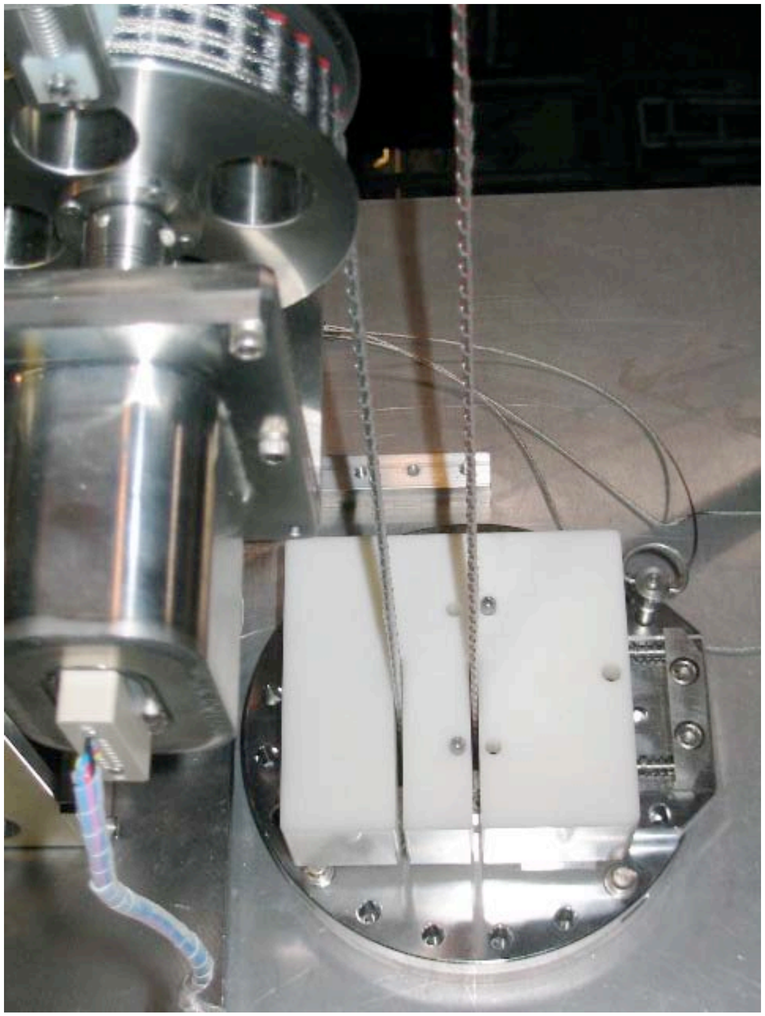
2. Software simulation for pole position:
   what happens if I raise or lower this cable? √

3. Method to raise cable. √

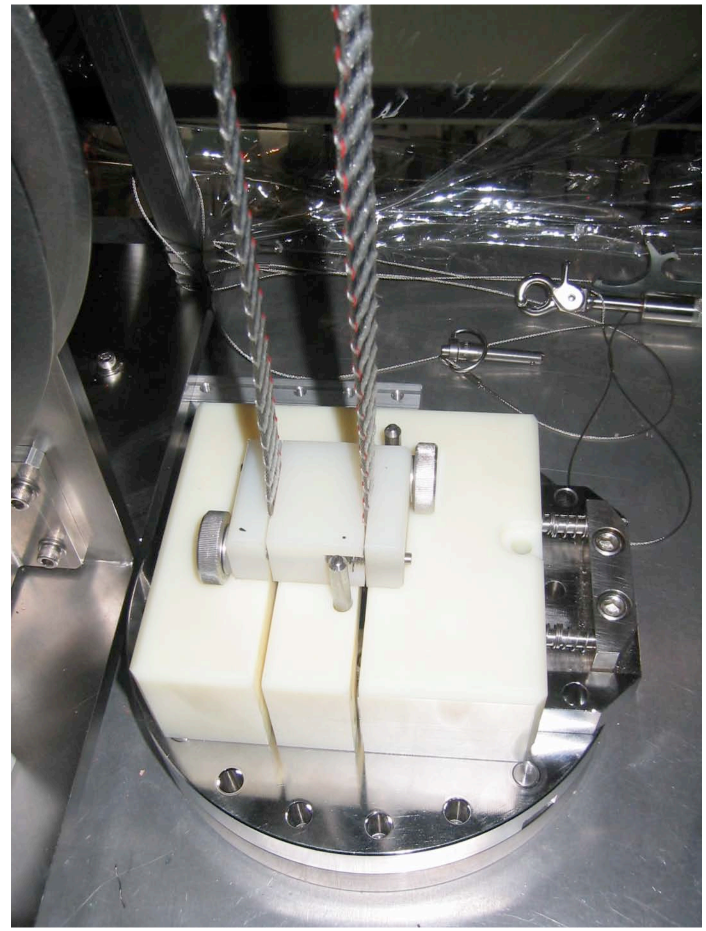
4. Method to lower cable. √

Securing the System

Normal Deployment



Emergency Locking Clamp



Software Simulation of Pole Position in Manual Mode

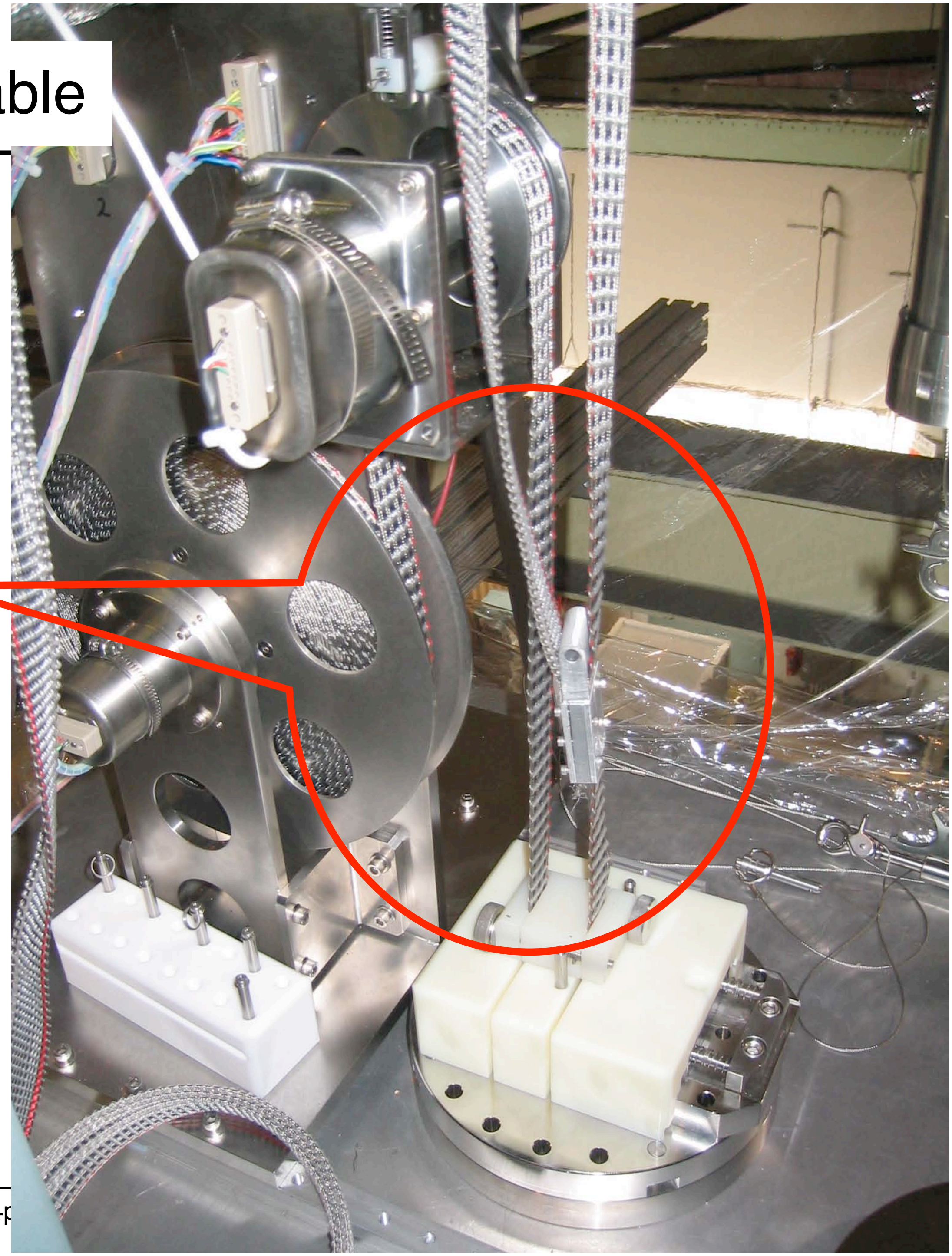
-> Run control program in simulated mode. (in place)

-> Proceed in small steps.

Method to Lower the Cable

Cannot unwind spools manually

Can use cable clamp to attach another cable



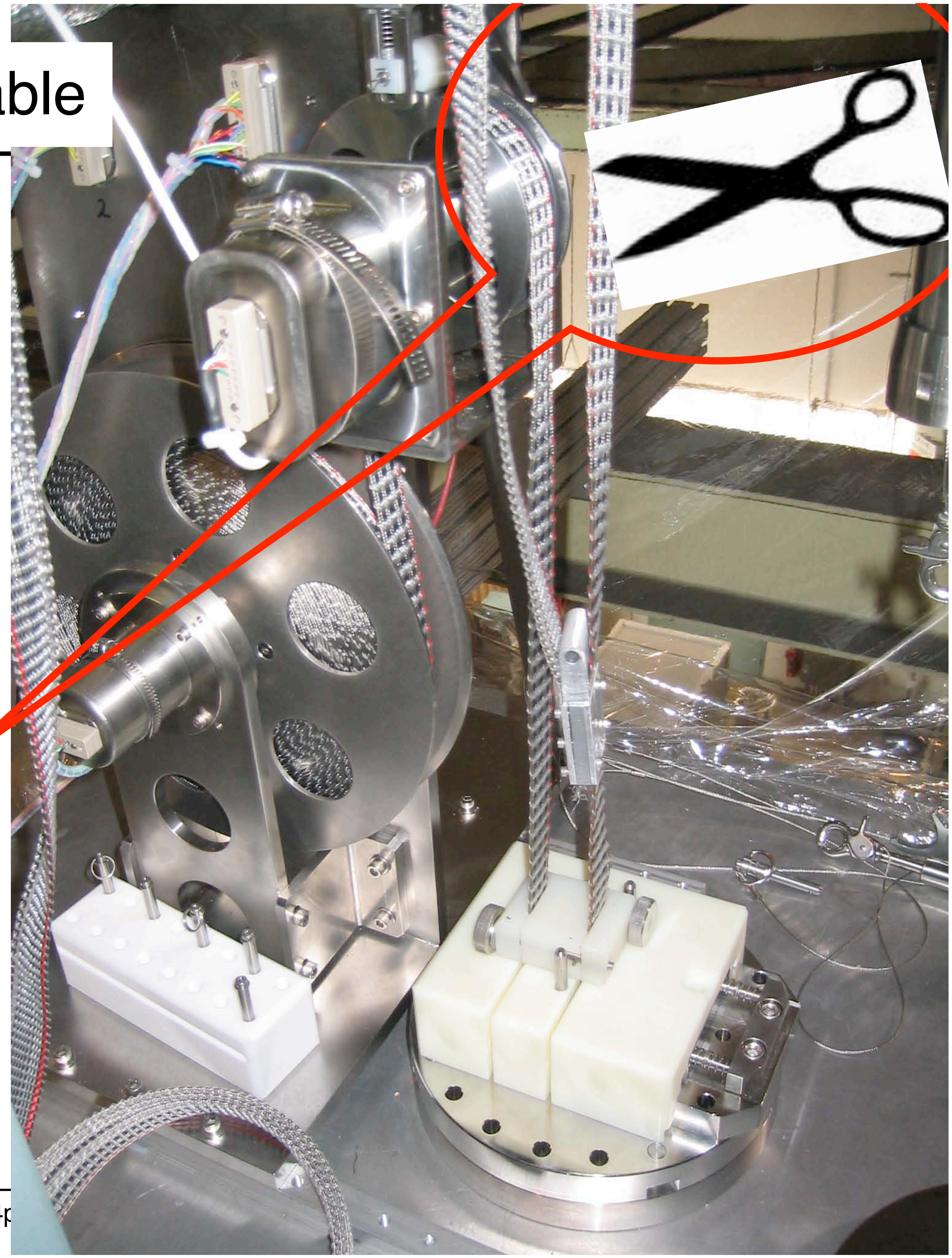
Method to Lower the Cable

Cannot unwind spools manually

Can use cable clamp to attach another cable

Cut cable connected to spool

-> Now we can manually lower cable.



Summary of Emergency Recovery

√ Easy recovery from power, software, or computer problems.

√ Software runs on several platforms with Java.

X Cannot exchange motors or gears without opening penthouse.

√ Have basic tools to manually <u>raise or lower</u> the cables.

√ Have software to simulate steps of manual operation.

We may want to think about better tools for manual operation but…

It is possible to manually retract the pole!

Materials Compatibility & Fire Safety

Issues of Concern:

- Contamination of liquid scintillator in detector
- Fire hazard of liquid scintillator

Materials Used in Glovebox

Stainless
Teflon
Nylon
Gold
Lucite/acrylic
Viton
Titanium

→Tested in soak tests with liquid scintillator for compatibility

(measurement of attenuation length and U, Th, K backgrounds)

How do we ensure the cleanliness of the calibration pole?

General

Perform LS soak or wet swipe test with LS or acid and background counting of all parts to be immersed in detector. When finished place cables, pivot block, and pole segments and instrumentation units in LS soak with continuous nitrogen purge.

Items to be introduced in LS:

1. Cable (stainless, nylon, teflon)
2. Pole segments (titanium)
3. Pivot block (stainless, teflon)
4. Instrumentation units (lucite, stainless, nylon)
5. IU cable connections (nylon, teflon, gold)

How do we ensure the cleanliness of the calibration pole?

1. Cable (stainless, nylon, teflon)
   -> UHV clean
   -> LS soak + background counting
   -> extended nitrogen purge

2. Pole segments (titanium)
   -> UHV clean
   -> alcohol, LS, and acid(?) swipe test + background counting

3. Pivot block (stainless, teflon)
   -> UHV clean
   -> nitrogen purge

4. Instrumentation units (lucite, stainless, nylon)
   -> “cleaning procedure for lucite containers”
   -> nitrogen purge

5. IU cable connections (nylon, teflon, gold)
   -> UHV clean
   -> nitrogen purge

Low-Background Counting of Materials

Results from Analysis of KamLAND 4pi soaks

Sample	LS mass[g]	Sample mass[g]	Counting time [days]	^{210}Pb [cpd]	^{226}Ra [cpd]	^{40}K [mBq]	^{208}Tl [mBq]	^{212}Pb [mBq]	^{214}Pb [mBq]	^{214}Bi [mBq]	^{228}Ac [mBq]
Nylon mono-filament cable part	71.129	0.0722	6.9613	3.23±1.55	0.934±1.36	2.14±1.13	0.21±0.17	0.19±0.13	0.47±0.39	0.39±0.10	0.37±0.90
Titanium	77.869	5.415	12.034	4.90±1.13	2.12±1.05	1.40±0.73	0.10±0.11	0.08±0.10	0.30±0.27	0.29±0.75	0.44±0.67
Stainless Steel Cable Part	76.4	3.7167	6.0605	1.57±1.50	-0.50±1.43	4.10±1.26	0.11±0.16	0.18±0.14	0.88±0.43	0.29±1.06	0.08±0.94
Teflon Conductor	71.679	0.8051	5.8095	1.55±1.56	0.95±1.61	2.39±1.08	0.21±0.18	0.11±0.13	0.50±0.46	1.34±1.32	-0.61±0.93
Connector (motors, possible transducers)	79.889	25.3037	6.1776	0.89±1.47	2.10±1.47	1.12±1.03	0.23±0.20	0.22±0.14	0.47±0.39	0.56±1.15	-0.31±0.87
Blank	78.6	----	5.6637	5.65±1.61	-0.53±1.45	1.92±1.07	0.24±0.17	-0.03±0.14	0.44±0.21	0.63±1.19	-0.19±0.87
Second Soak in Sept.											
Blank (1 - 4)	67.1	----	15.6225	1.15±0.96	1.18±0.99	23.5±7.1	1.3±0.5	0.6±0.9	20.2±1.7	20.1±2.8	4.8±2.0
Cable with Red wire	65.3	11.3	5.3521	3.18±1.62	-0.65±1.54	39.0±13.3	1.9±0.1	2.6±1.4	7.4±2.0	0.5±2.0	6.9±3.2
Cable with Red wire (After external Cleaning)	46.9	11.3	12.9873	5.89±0.95	0.65±0.84	26.0± 7.5	2.2±0.6	0.7±0.8	1.0±1.1	2.8±2.0	3.8±1.9

Low-Background Counting of Materials

Results from Analysis of KamLAND 4pi soaks

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Titanium	77.869	5.415	12.034	4.90±1.13	2.12±1.05	1.40±0.73	0.10±0.11	0.08±0.10	0.30±0.27	0.29±0.75	0.44±0.67
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Connector (motors, possible transducers)	79.889	25.3037									
Blank	78.6	----									
Second Soak in Sept.											
Blank (1 - 4)	67.1	----									
Cable with Red wire	65.3	11.3									
Cable with Red wire (After external Cleaning)	46.9	11.3									

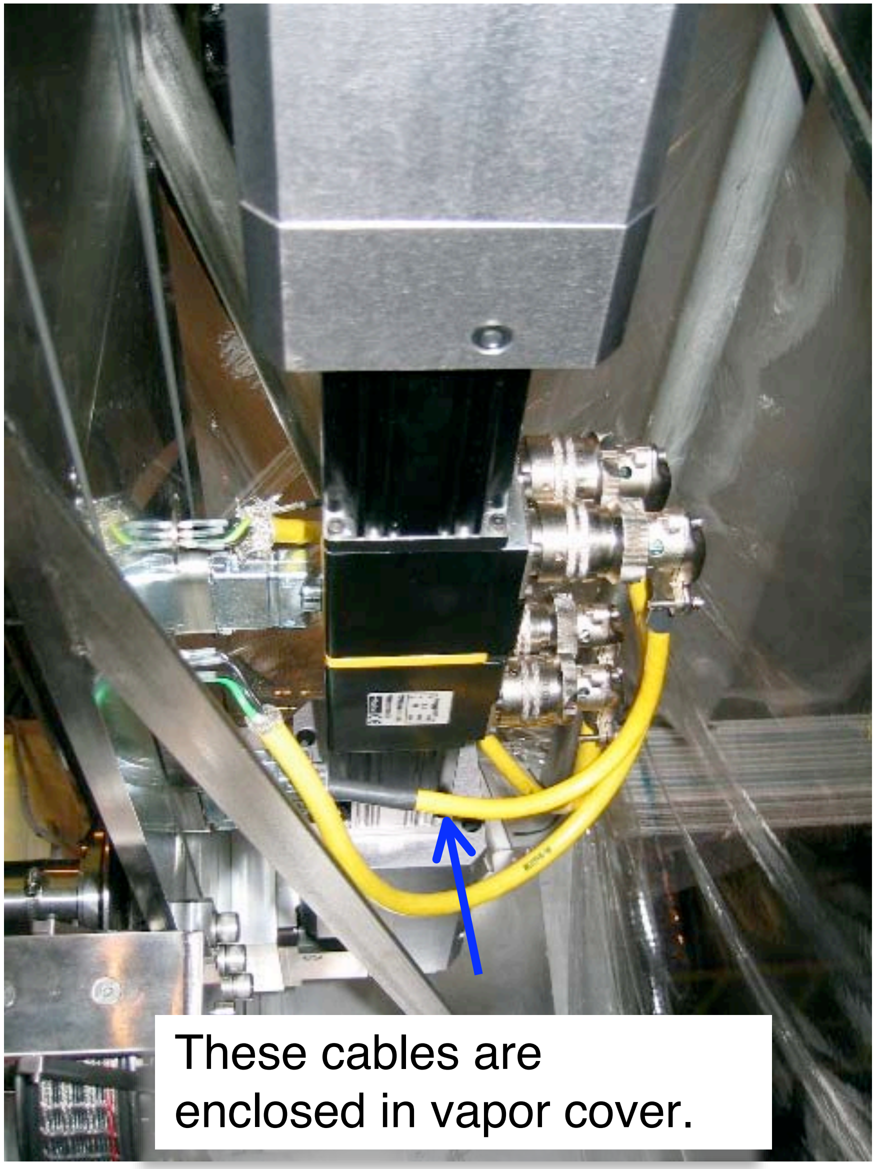
Recent Re-count of Cable Soak Samples

40K [mBq] before: 39.0 +/- 13.3 current: 26.0 +/- 7.5
208Tl [mBq] before: 1.9 +/- 0.1 current: 2.2 +/- 0.6
228Ac [mBq] before: 6.9 +/- 3.2 current: 3.8 +/- 1.9

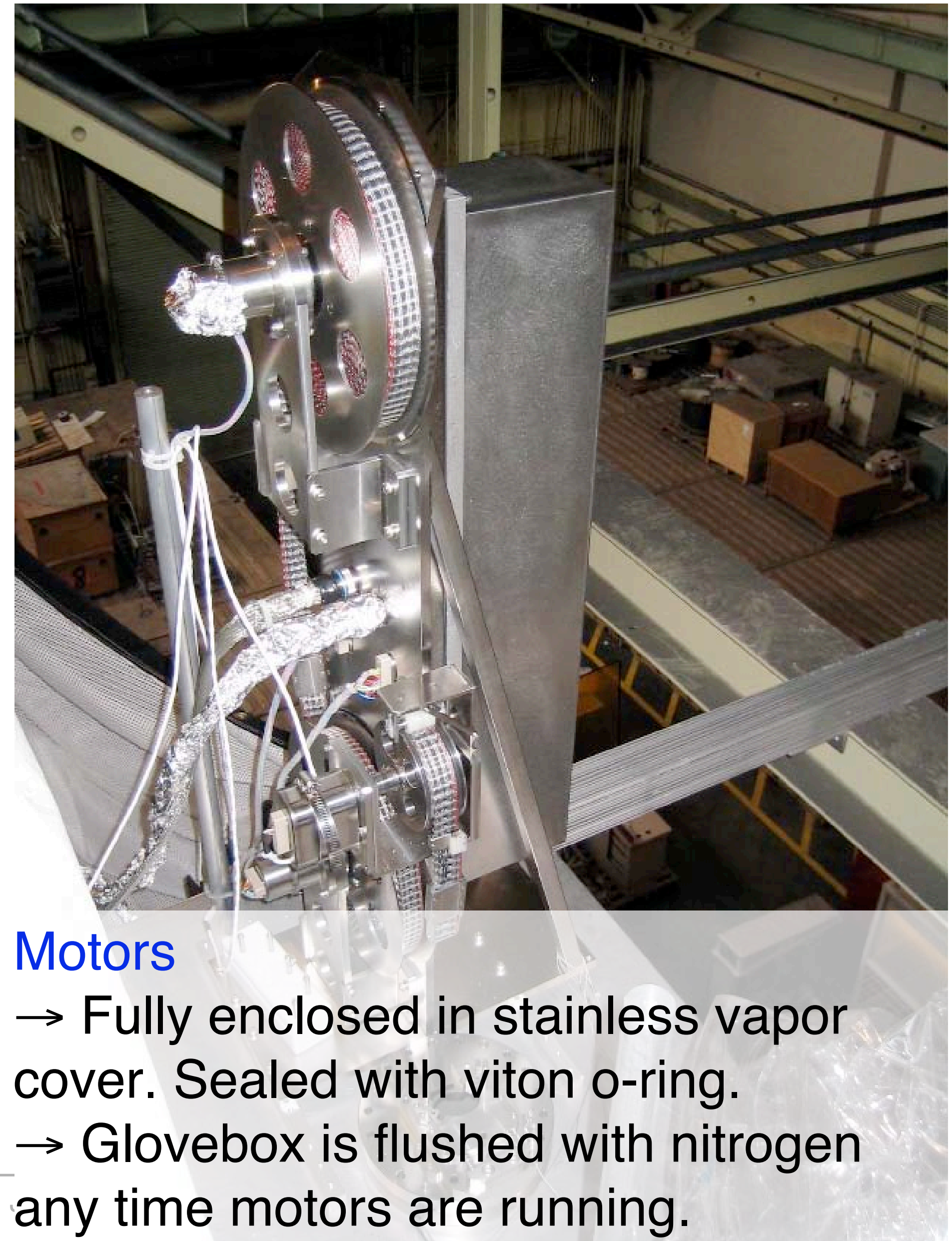
Scaled to the 4pi by g/ft and 120 ft of cable gives 6.3 Bq of 40K and 0.7 Bq of Th being introduced into the detector with a greater than 3
sigma confidence level.

→Prepare new cable soak samples, improve cleaning procedures and recount

Motor Cover



These cables are enclosed in vapor cover.

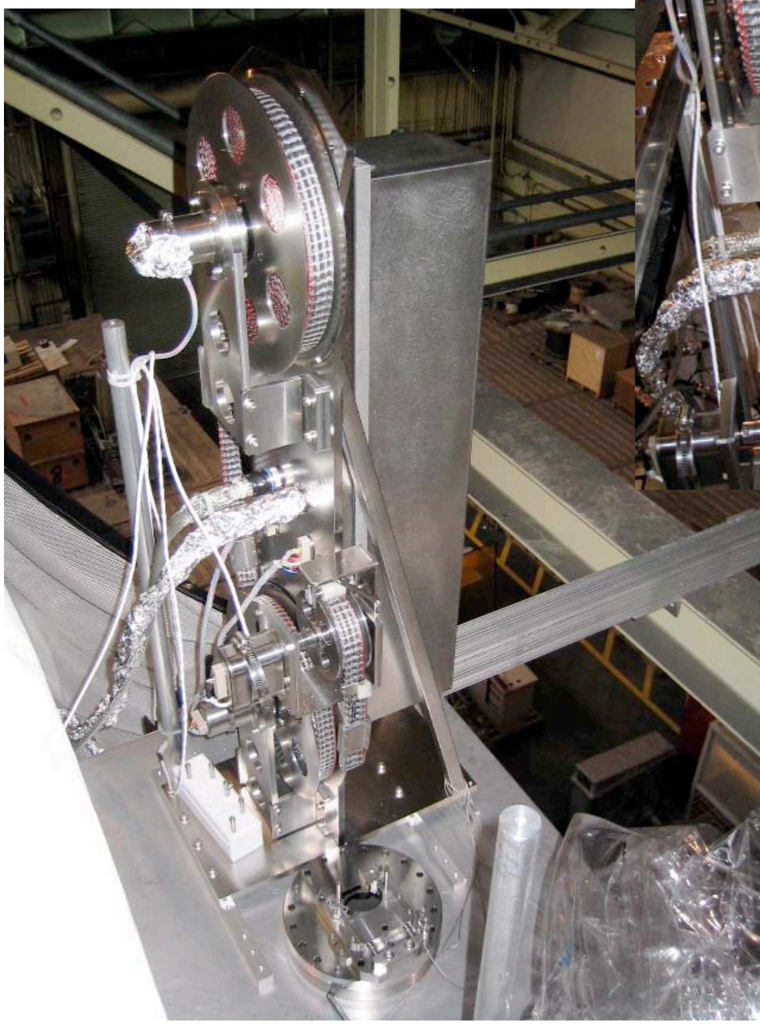


Motors

→ Fully enclosed in stainless vapor cover. Sealed with viton o-ring.

→ Glovebox is flushed with nitrogen any time motors are running.

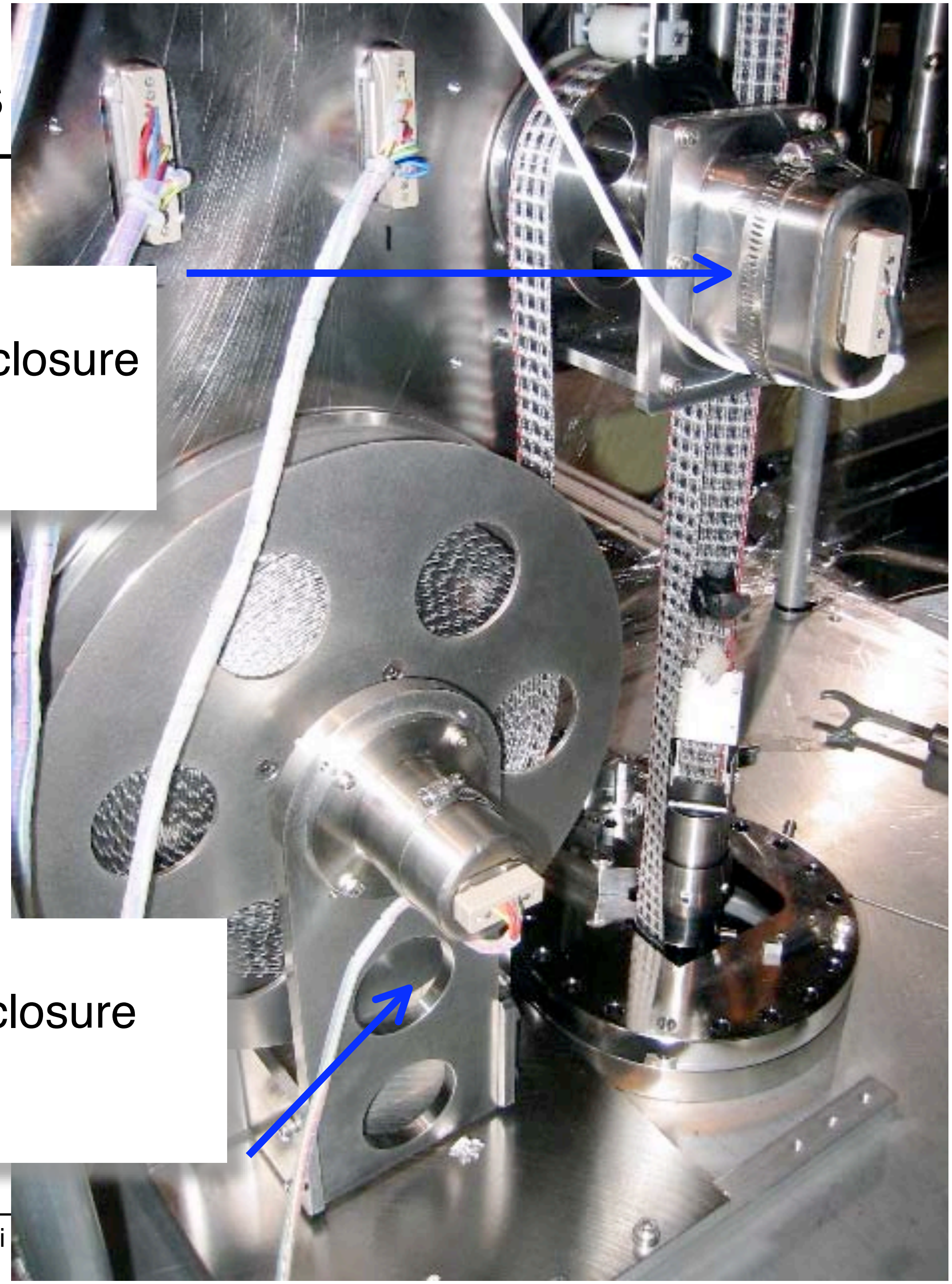
Operating Temperature of System



Surface temperature of cover is at room temperature.

Motors do not get warm.

Slip Rings and Encoders



Encoders

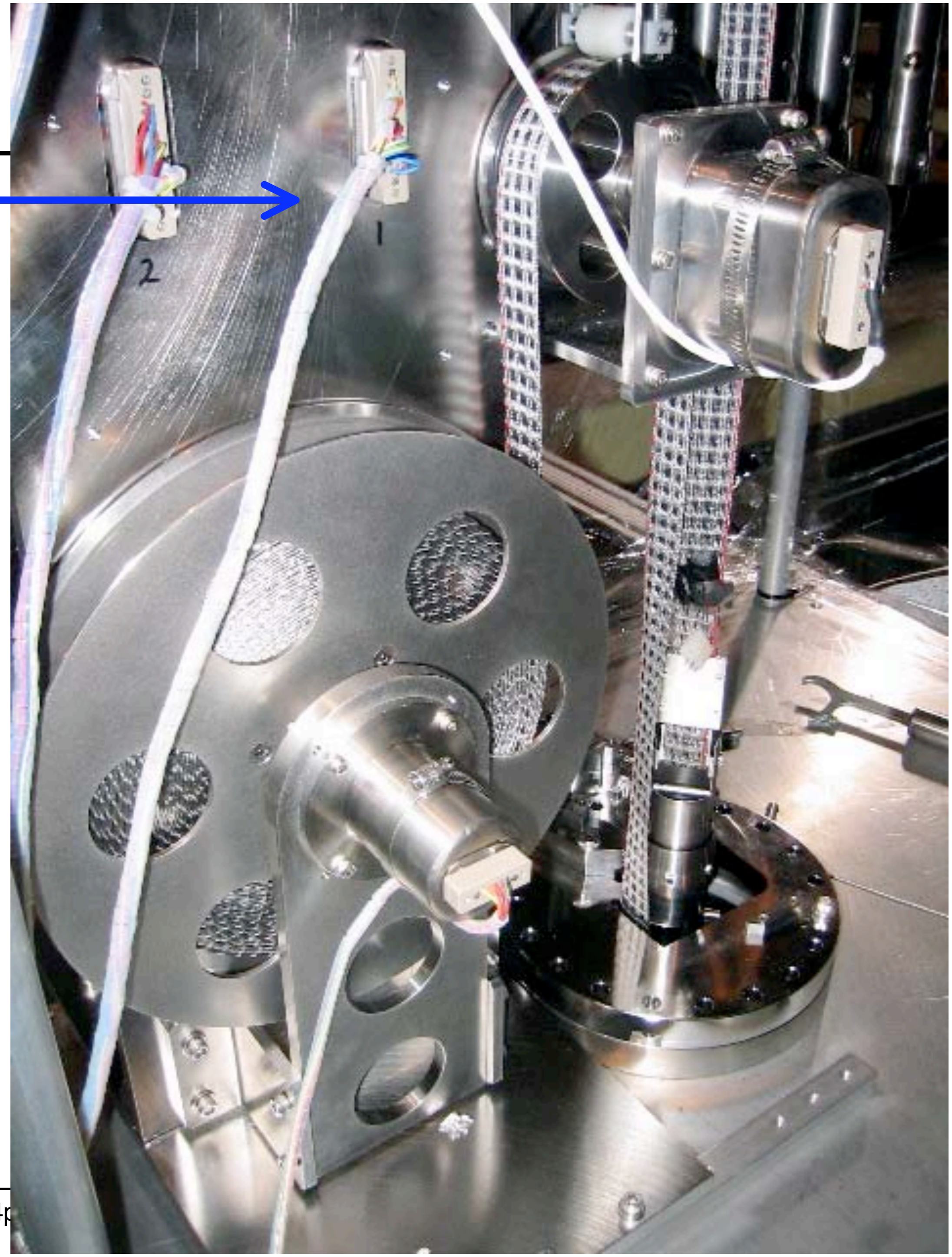
enclosed in stainless enclosure
weld-in feedthrough
readout by teflon cable

Slip rings

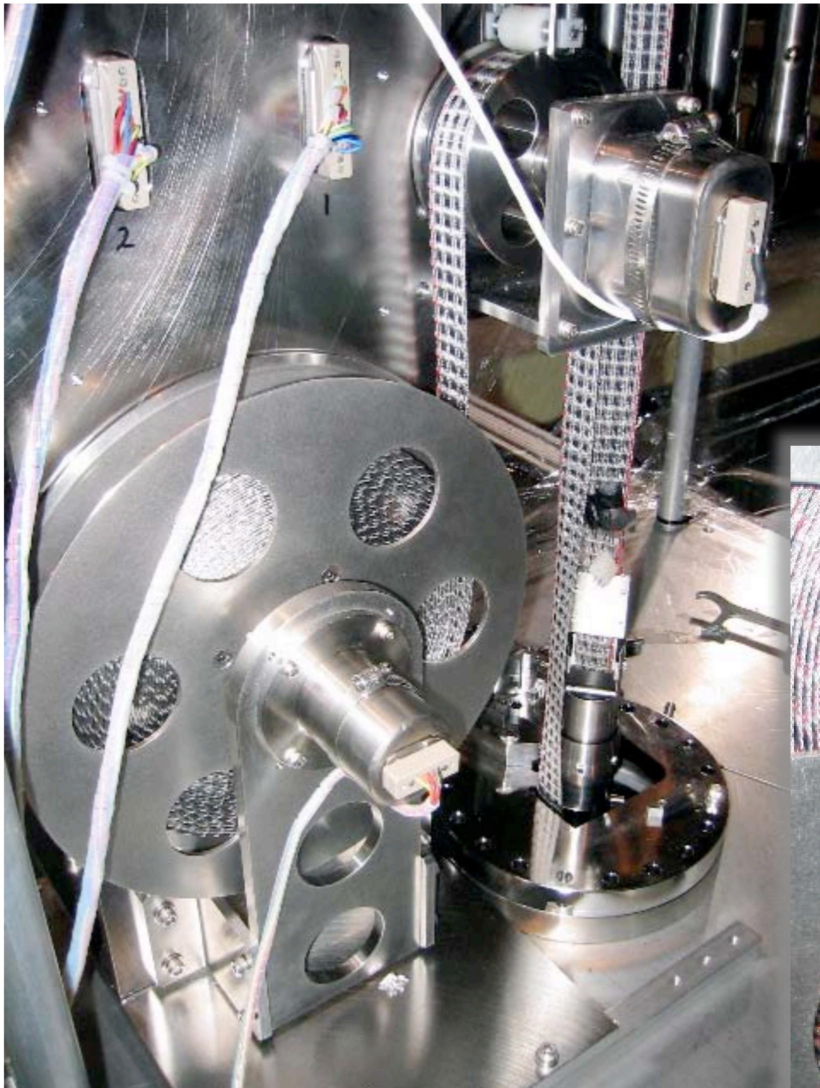
enclosed in stainless enclosure
weld-in feedthrough
readout by teflon cable

Motor Control Cables

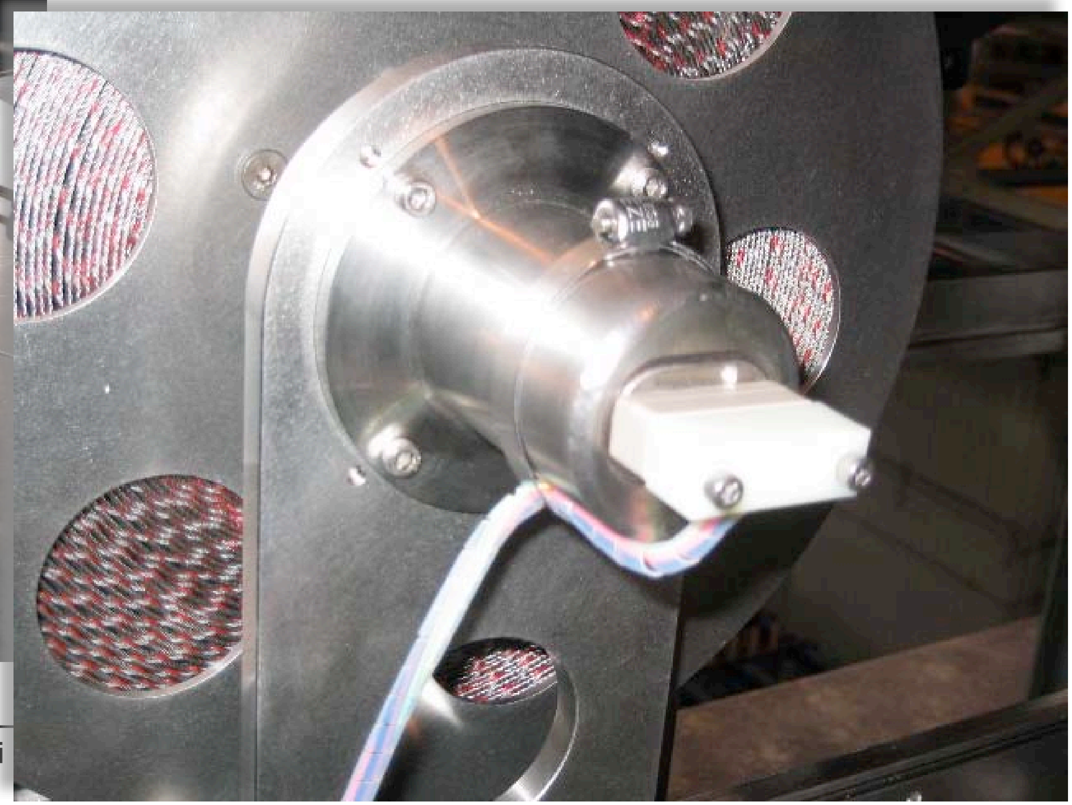
Teflon cable



Nylon Covers for D-sub Connectors



Fabricated covers for all in-glovebox connectors after KamLAND review of 4pi system



4pi Feedthrough Panel

Removable plate with viton seal

Weld-in feedthroughs

Status & Summary

KamLAND 4pi Workshop, May 15-17, 2005

Web site with links to talks and notes from discussion

http://kmheeger.lbl.gov/kamland/4pi/reviewmay05/

Participants

M. Koga (Tohoku University)
K Nakamura (Tohoku University)
Y. Kishimoto (Tohoku University)
T. Classen (University of Alabama)
J. Foster (University of Alabama)

+ Berkeley 4pi group

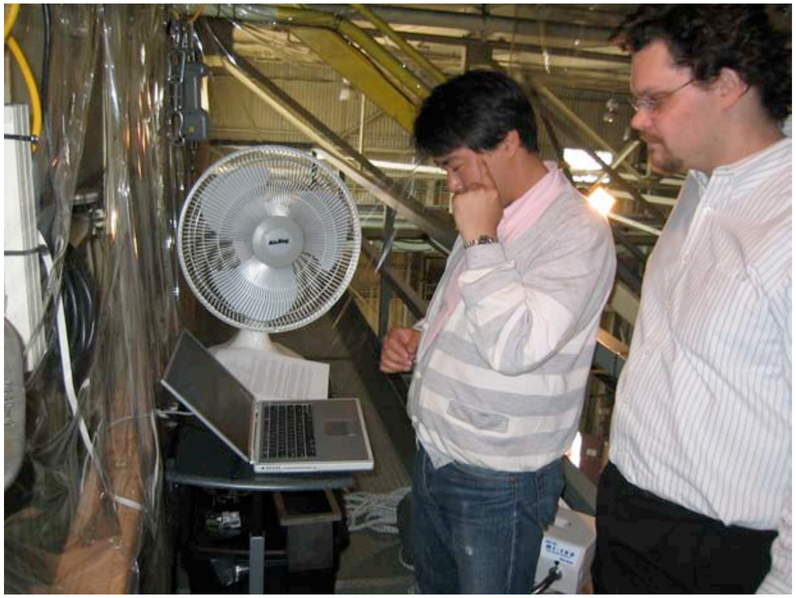
Training of Operators

Current z-axis Experts on New Deployment System

Andrew Franck, Fred Gray, Bruce Berger, Karsten Heeger
Lindley Winslow

Started Training at LBNL

Kengo Nakamura (RCNS), Tim Classen (UA)



Continued training during commissioning process on site. Extensive z-axis runs prior to off-axis deployment for system testing and calibration.
→ Numerous opportunities for training.

Summary & Outlook

- Online positioning with control software accurate to ~3-4 cm.
Do not expect to calibrate much beyond R=5.5m. Balloon at R=6.5m with a position uncertainty/variation of about ~20cm)
→ sufficient for safe deployment

- Off-line position reconstruction with Co-60 sources to about 0.5cm.
→ sufficient for source reconstruction

Fiducial volume: R < 5.5 m

$\Delta R_{FV} = 5$ cm → $\Delta V = 2.7\%$
$\Delta R_{FV} = 2$ cm → $\Delta V = 1.1\%$

- Finish surveying of system with different pole configurations.
→ in progress

- Complete materials certification of epoxy for instrumentation unit (load test, background count, soak test)
→ in progress, epoxy used in the past, expects to pass

-Resolve issue of 40K signal in liquid scintillator soak of cable.
- in progress, origin not understood, questions about samples.